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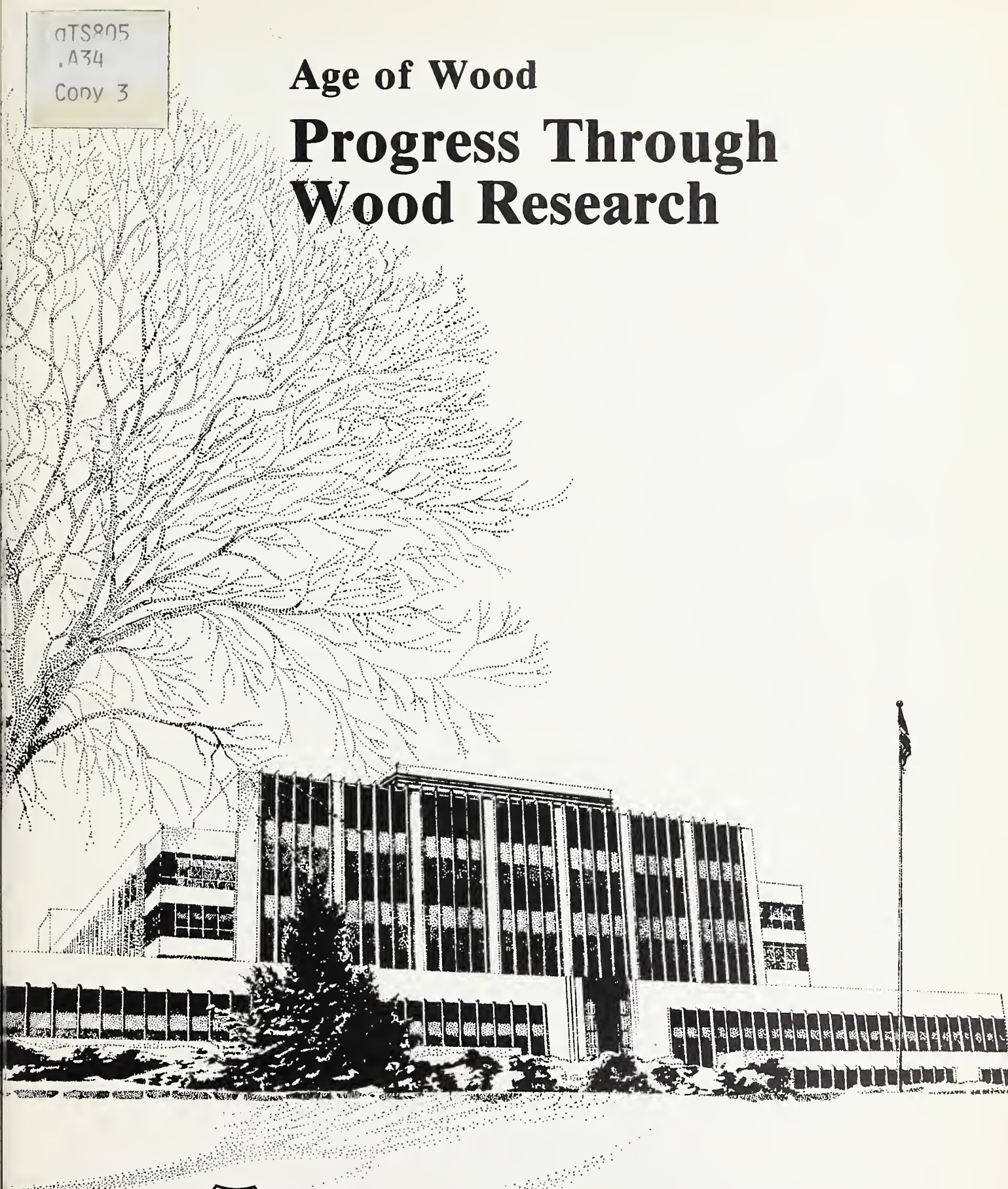
Age of Wood

Progress Through Wood Research



United States
Department of
Agriculture

Forest
Service

Forest
Products
Laboratory

FPL Research Topics

Material Properties and Construction

Preservation and Protection

Chemicals and Energy

Biotechnology

Mycology

Pulp and Paper

Packaging

Anatomy and Identification

Composite Products and Adhesives

Timber Requirements and Economics

Processing of Lumber

AD-33 Bookplate
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June 1985

Forest Products Laboratory. Age of Wood: Progress Through Wood Research. Madison, WI: U.S. Department of Agriculture, Forest Service, 1985. 29 p.

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Age of Wood

Progress Through Wood Research

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Director's Message

Friends:

This issue of "Age of Wood" marks a special anniversary for our unique institution. In 1910, 75 years ago, a visionary group of scientists joined forces here in Madison, acting on the belief that good research in wood products would ensure the inexhaustibility of that most majestic of our Nation's natural resources—our forests.

The Forest Products Laboratory (FPL) has helped extend the world's supply of wood through more efficient raw material use, through increased product longevity, and through creative product development. We have been a world leader in all aspects of fundamental wood research, greatly expanding the understanding of wood chemistry, biochemistry, physics, wood properties, and engineering. Through this basic research we have developed laminated timbers sturdy enough to carry a railroad train and span a sports arena; we have helped make paper strong enough to transport steel parts and soft enough to catch a baby's sneeze; and we have derived chemicals providing the basis for industrial development.

We at FPL today take pride in these and many other accomplishments. And with pride we offer this document to you, the American public, confident that you will recognize in these achievements the ideas and products through which wood has made all of our lives better.

FPL is now in a new age of technological development. We have instruments and methodologies that will permit us to explore the use of wood in ways only dreamed of by earlier wood scientists. We are developing a new generation of wood science that will continue to support the unique position of wood—our Nation's primary renewable resource—in the future. The Forest Products Laboratory is determined to continue to be a leader in the new era of wood use.

John R. Erickson, Director
Forest Products Laboratory

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Introduction

The Forest Products Laboratory was established by the Forest Service of the U.S. Department of Agriculture in 1910 in Madison, Wisconsin. It was to serve as a centralized wood research laboratory to ensure that our Nation's forest resources would always provide the greatest good for the greatest number.

Forest Service research on wood products actually began before the turn of the century, concentrating on wood properties, preservatives, and chemistry. It soon became apparent that a single central laboratory was essential to consistent, reliable research results.

So in 1910, with the support of the University of Wisconsin, a staff of 45 young researchers began work at the new Forest Products Laboratory (FPL). As the only institution of its kind at the time, FPL had no precedent to follow. As a national laboratory, its mandate was broad: To explore the field of wood utilization for the benefit of the people and for the perpetuation of the resource. The approach was threefold: To increase the serviceability of wood products; to develop new uses of wood and improve existing ones; and to augment the usefulness and quality of all species.

We present here a view of FPL research. The eleven subject areas hint at the interrelated problems in studying wood. As the product of a living tree, wood is a complex array of discrete chemical structures, bound in ways that both enhance and complicate its usefulness. To fully understand and exploit that usefulness, FPL researchers must take an interdisciplinary approach—for example:

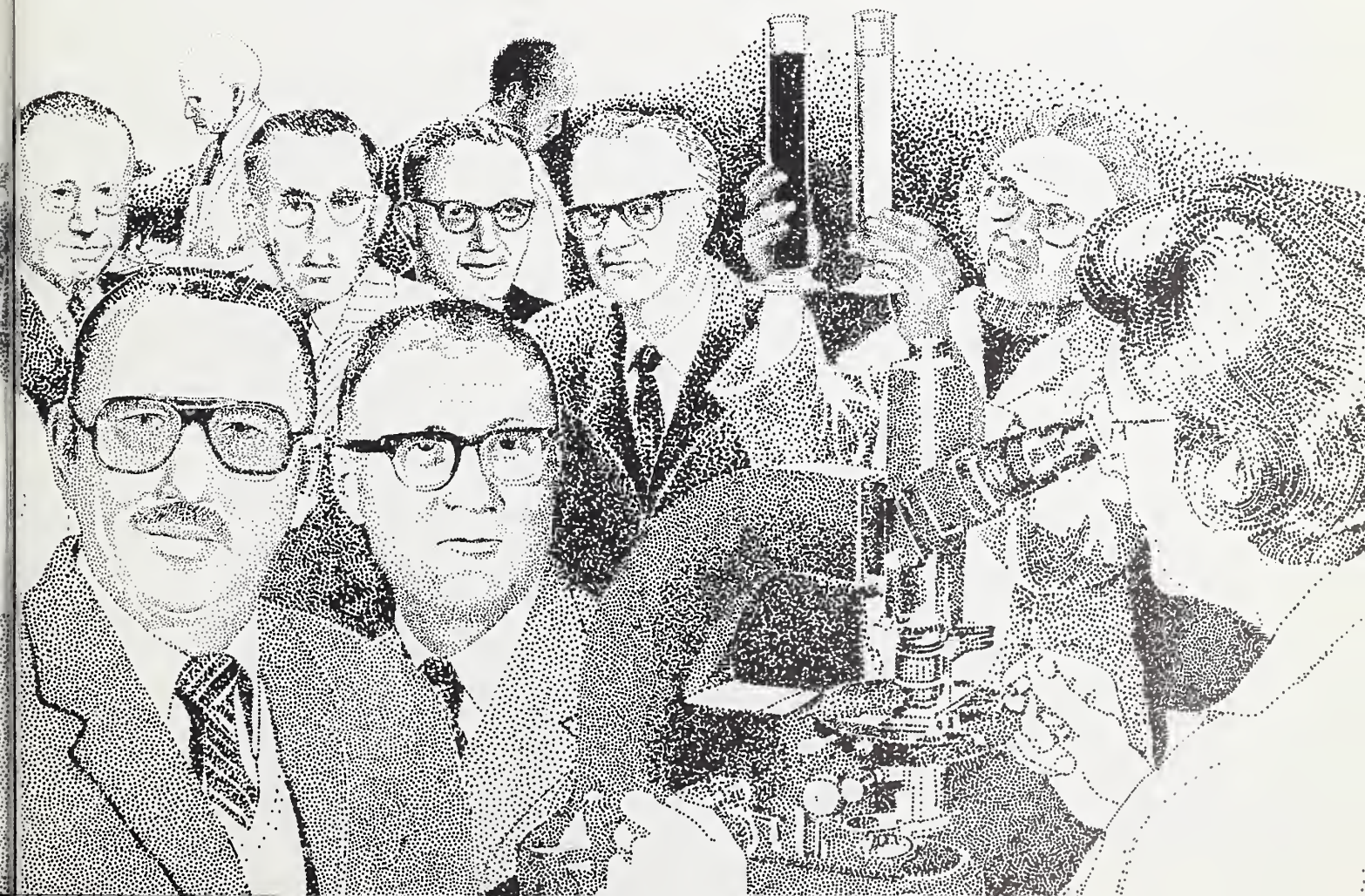
Pulping researchers rely on a knowledge of wood chemistry and physics;

Preservative chemists depend on a solid foundation in mycology and pathology;

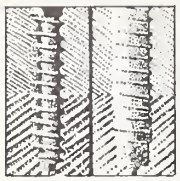
Engineers must understand wood anatomy.

These various disciplines have interplayed over the years, shifting roles as advancing technologies in one area have influenced another. The Nation's changing needs from peacetime through wartime, from prosperity through depression, have also shaped the direction of FPL research. But the Lab's mandate and approach have never changed. We continue our quest for basic and practical knowledge, to permit the wisest use of our national wood resources.

We invite you to review with us some of our past achievements and to look with us into the future for more economical, efficient, and reliable processes, products, and ideas to provide the greatest good for the greatest number.



Material Properties and Construction



It was perhaps research on timber properties that made apparent the need for the national wood-testing center that was to become the Forest Products Laboratory. That testing of "timber" continues today in a wide array of research projects on material properties and construction.

Because timber testing was recognized early as both an industrial engineering problem and an important aspect of forest management, the brand-new FPL found its fund of knowledge in engineering already becoming well established. Researchers concentrated on the fundamental problems of determining the mechanical properties of wood and wood products. They evaluated the effects of fire, drying, and preservatives on mechanical properties, and prepared lumber grading rules. FPL's broadening of the species base in wood utilization also had a strong and favorable impact on national forest management.

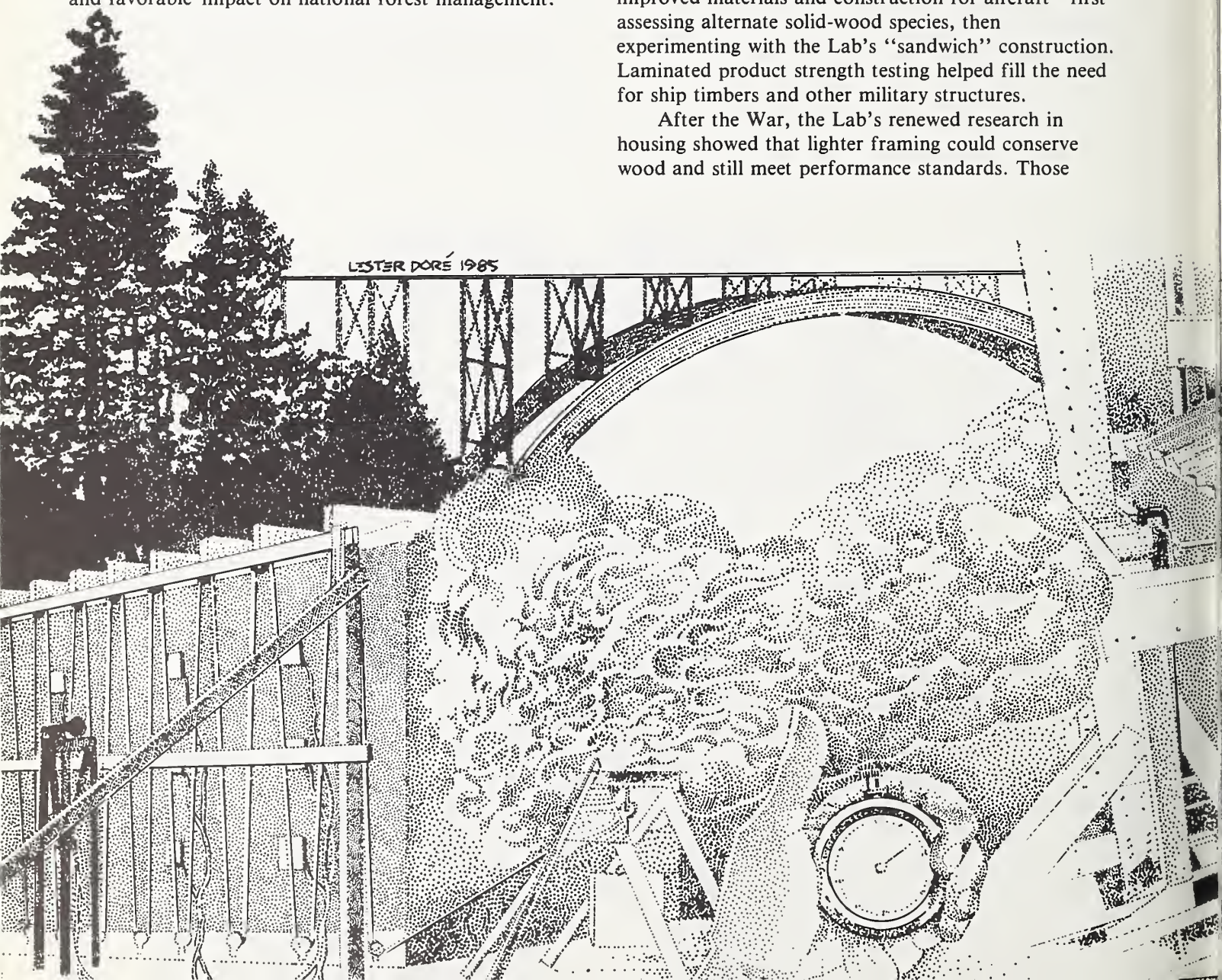
Researchers in the 1920's discovered improvements in working with steaming and bending processes for the furniture industry, and developed the equipment for testing large structural members, expanding the Lab's ability to develop design data for wooden columns used in buildings, bridges, and other such structures.

Large-scale construction research was successful in the design and economics of the laminated arch in the 1930's. Exhaustive screening of appropriate fasteners and joint configurations provided the basis for today's industry standards. The broad public need for information on the engineering properties of wood and the Lab's wealth of knowledge complemented each other in the publication of the first edition of the *Wood Handbook* in 1935.

Expanded fire-testing facilities and the development of the "stressed-skin" principle, prefabricated wall units, and improved moisture barriers also were part of the group's contribution in that busy decade.

When WWII broke out, FPL engineers sought improved materials and construction for aircraft—first assessing alternate solid-wood species, then experimenting with the Lab's "sandwich" construction. Laminated product strength testing helped fill the need for ship timbers and other military structures.

After the War, the Lab's renewed research in housing showed that lighter framing could conserve wood and still meet performance standards. Those

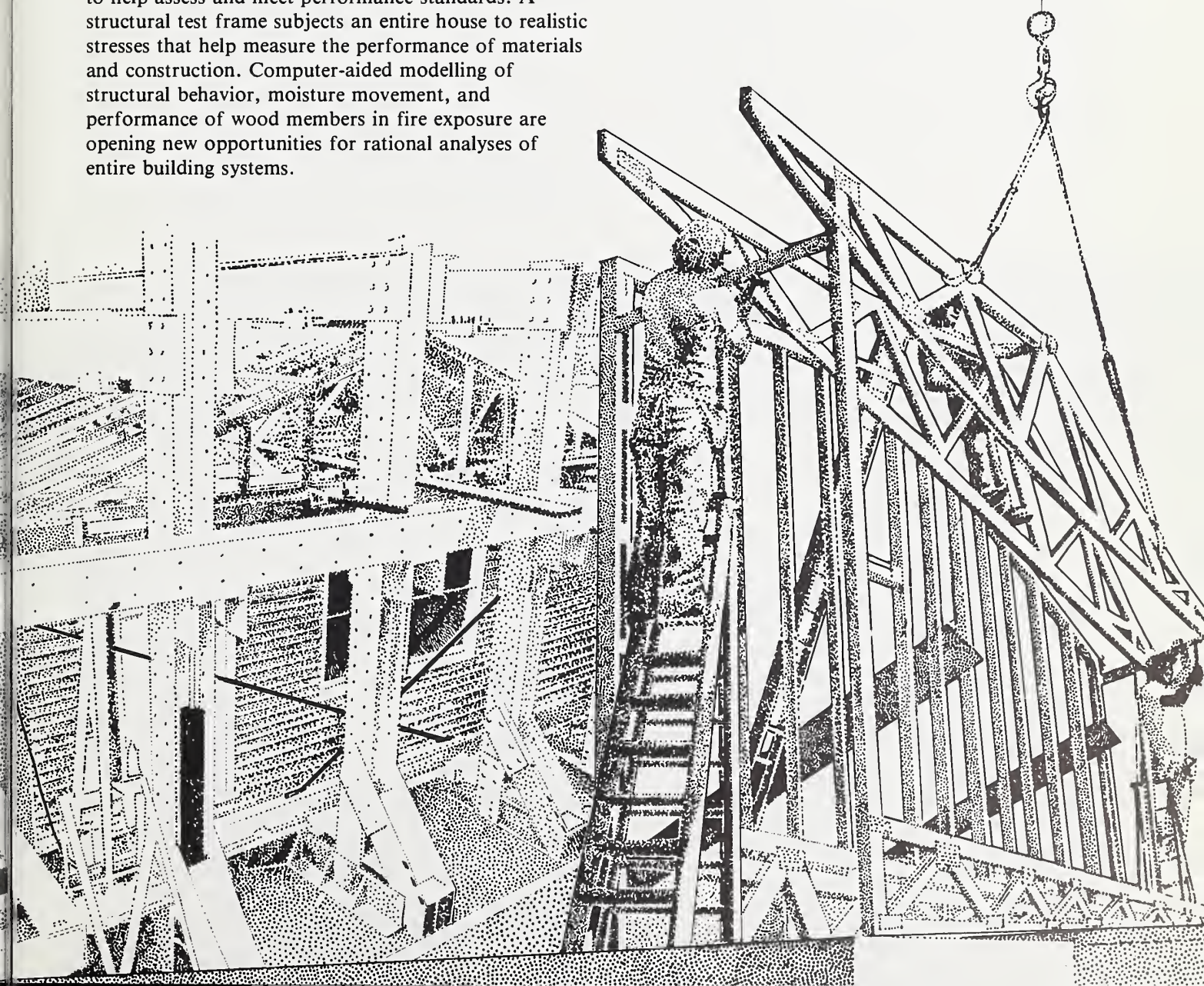


principles were supported by the Lab's definitive book on construction techniques for the homebuilder. Lab engineers developed a series of plans for more affordable housing, and studied earthquake and tornado damage to better understand a buildings's response to natural forces.

As homeowners of the 1970's increased their awareness of ecological concerns and the need for energy conservation, the Lab responded with guidelines for thermal insulation, moisture and noise control, and renovation and remodelling techniques. The concerns of economy, strength, and speed in new construction were met in FPL's Truss-Framed System, a prefabricated system suitable for framing small houses and commercial buildings.

Now, in the 1980's, basic work in determining strength properties of members and systems continues, with the continuing assessment of lumber grades, effects of environmental conditions, loads, constructions, fasteners, and treatments. Building components are mathematically modelled and analyzed to help assess and meet performance standards. A structural test frame subjects an entire house to realistic stresses that help measure the performance of materials and construction. Computer-aided modelling of structural behavior, moisture movement, and performance of wood members in fire exposure are opening new opportunities for rational analyses of entire building systems.

Future research will quantify the effects of environmental conditions and treatments on lumber properties. Our research in grading will allow us to accommodate the switch to the future timber resource. We will be able to standardize design procedures for fasteners. Surer predictions of fire behavior and better treatments for fire resistance will alleviate a long-standing concern in the use of wood-base materials. And our research will always focus on more reliable, more efficient design and construction of wood-frame building systems. Responding to changing needs, hand-in-hand with developing new technologies, FPL research in material properties and construction will ensure that the Nation's wood supply is used to our best advantage.



Preservation and Protection

The young Forest Service recognized in the 1880's that efforts toward "conservation through wise use" would have to be directed at increasing the durability of wood products in use. That attitude toward wood preservation, a major force in the development of a national laboratory, gave preservation and protection an emphasis that is still central among the thrusts of Forest Products Laboratory research today.

From its earliest work on preservatives for railroad ties, telegraph poles, and mine timbers, the Forest Service expanded its expertise in protecting wood from decay. When FPL ushered in its first visitors in 1910, the Section of Wood Preservation Research showed off complete facilities for fundamental and applied research.

The Lab's first efforts included establishing the physical and chemical properties of preservatives, their effect on wood strength, their ability to penetrate wood, their efficiency in preventing the growth of wood-destroying fungi, and the diagnosis and classification of decay.

Early fire research was an integral part of that first decade. The group studied natural resistance, chemical treatments, treating processes, and performance in simulation tests; paint was one of the fire study subjects.

The post-WWI efforts of the group made strides in characterizing wood surfaces and clarifying the functions of primers and paints.

These principles proved to be the group's greatest contribution to the Army efforts in WWII, saving money in the maintenance of thousands of buildings. Cooperation with the Navy led to extensive testing of treatments against wood-boring marine organisms.

Housing needs in the 1950's demanded the researchers' attention. They developed guidelines for decay control, on-site treatments during construction, the "FPL Natural Finish" for redwood and cedar siding, and safe, affordable termite control.

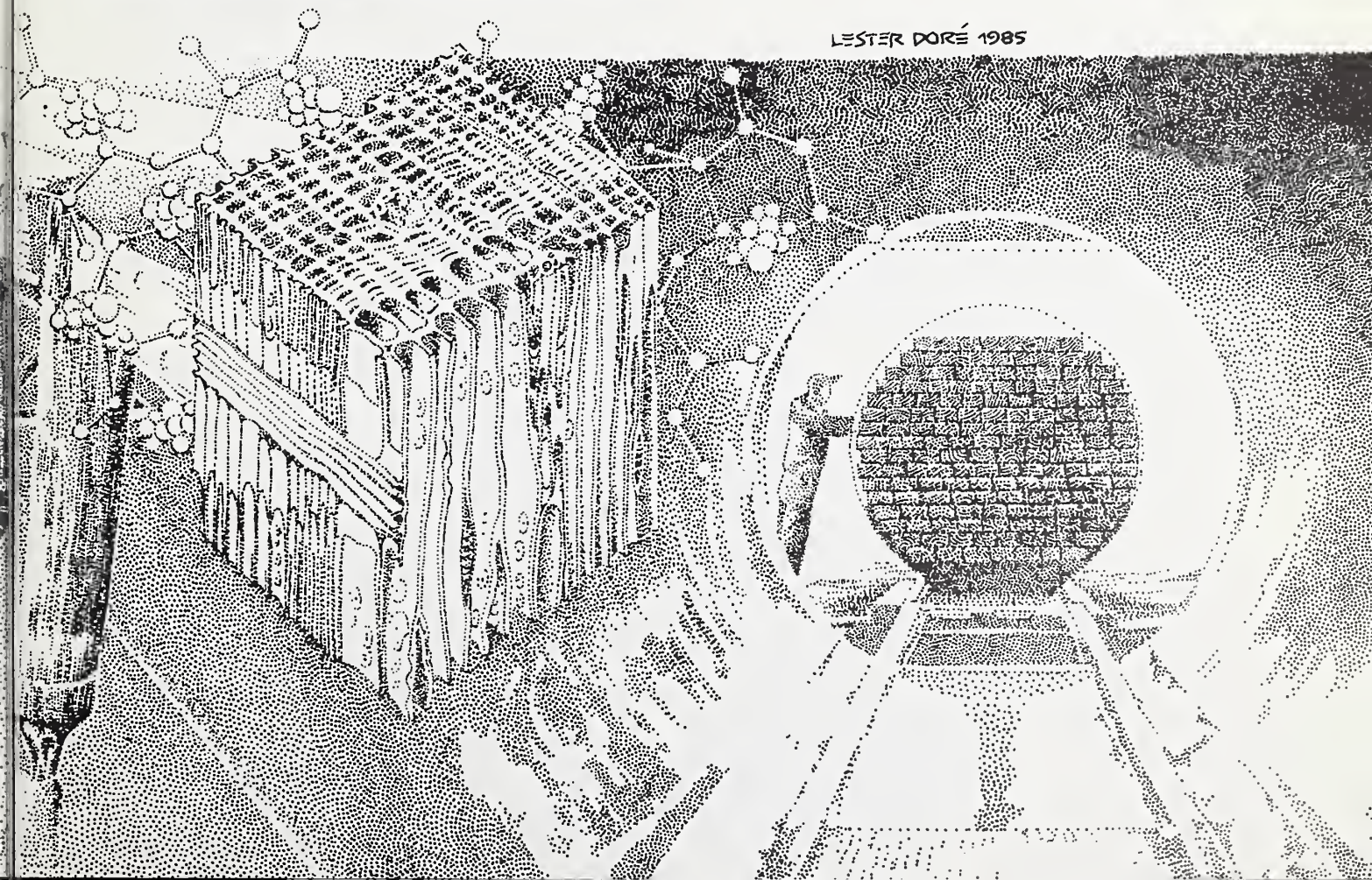
Renewed emphasis on basic research brought about new approaches to studying decay. With the "soil-block test" for accelerated fungal growth studies, and with the explosion of electronic tools, advanced microscopy, and radioactive assay systems, FPL scientists in the 1960's plunged into determining the pathways of fungal invasion into wood cells, characterizing enzymes of decay, culturing plant-tissues, probing natural decay resistance in timbers, and understanding the enzymatic and nonenzymatic metabolites in carbohydrate degradation and the agents of lignin degradation.

Environmental concerns in the 1970's initiated a new look at preserving and protecting wood by treatments with reduced toxicity and with greater selectivity in their action. This led to fundamental studies to reveal weaknesses in the organisms that could be manipulated to interrupt the decay cycle. One possibility being explored now is inhibiting the synthesis of chitin, an essential component in the cell walls of fungi and in the "shells" of termites and marine borers. Another is the development of a specific, naturally occurring toxin designed to control termites. Pressed into an edible paper bait, it attracts termites and kills them with no harmful side effects on the environment.

Another broadly promising alternative in wood protection is bonding chemicals to wood to improve fire and decay resistance, dimensional stability, and resistance to ultraviolet light. The work, based on FPL's wood chemistry of the 1930's and 1940's, takes advantage of the strong bonds easily formed between wood and an array of organic chemicals. Future work in chemical modification of wood will define the reactions occurring and characterize the treated wood to help find the optimum uses.

Future research on wood finishing will develop treatments to make wood stable under ultraviolet light. Studies of the interactions of the wood surface, the finish, and pretreatments for stability against water will help to develop more reliable finish systems for wood used outdoors.

Through the future of wood preservation and protection in all its forms, we can ensure the durability of wood products and the wise use of our forests.



Chemicals and Energy

"Dendro-chemistry" they called it then, one of the three areas basic to the early Forest Service research program. Their earliest concerns were the efficient production of naval stores, and the improvement of systems for the production of chemicals and fuels from wood. In their modern versions, these are still among the central concerns of the Forest Products Laboratory programs in chemicals and energy.

FPL chemists were so eager to establish their research program that they began their work in a University of Wisconsin boiler room a year before the Lab was built. The major problems that faced the group were improving technical processes and refining products.

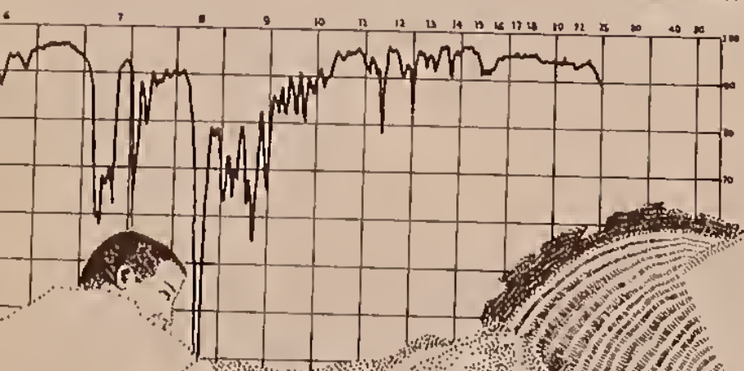
In that first decade, FPL researchers in naval stores work improved production processes for turpentine, resins, and rosins. In hardwood distillation studies, researchers defined reaction conditions, improved yields, and broadened the species base. In developing lab-scale techniques for the production of wood-alcohol, they demonstrated a possible use for wastewood. They also found that the lignin residue from alcohol production from sawdust could be used to make a denser charcoal for gas masks in WWI.

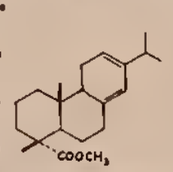
Progress in the 1920's was largely in such fundamental concerns as the locations of components—cellulose, hemicelluloses, lignin, and extractives—in wood, the separation of lignin from cellulose, the identification of wood components by microchemical analysis, and the development of new analytical chemistry methods. Flavorings, glues, resins, and alcohols were just a few of the chemicals refined or produced. Successes in these areas laid the groundwork for later studies in wood chemistry, pulp and paper technology, and biotechnology.

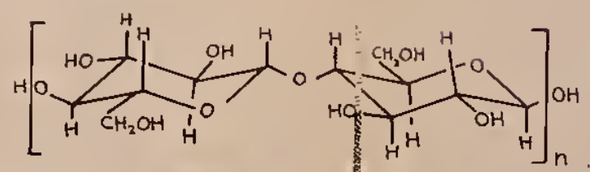
During the 1930's the most complex waste product of concern was lignin—the "glue" that holds wood together—largely a by-product of the pulping industry. FPL chemists developed a means of isolating lignin, allowing studies of its reactivity with chemical agents. Several projects were successful in forming certain plastic materials, such as "compreg," from chemical and mechanical treatments of combined wood components; some such products were put to use in aircraft during WWII.

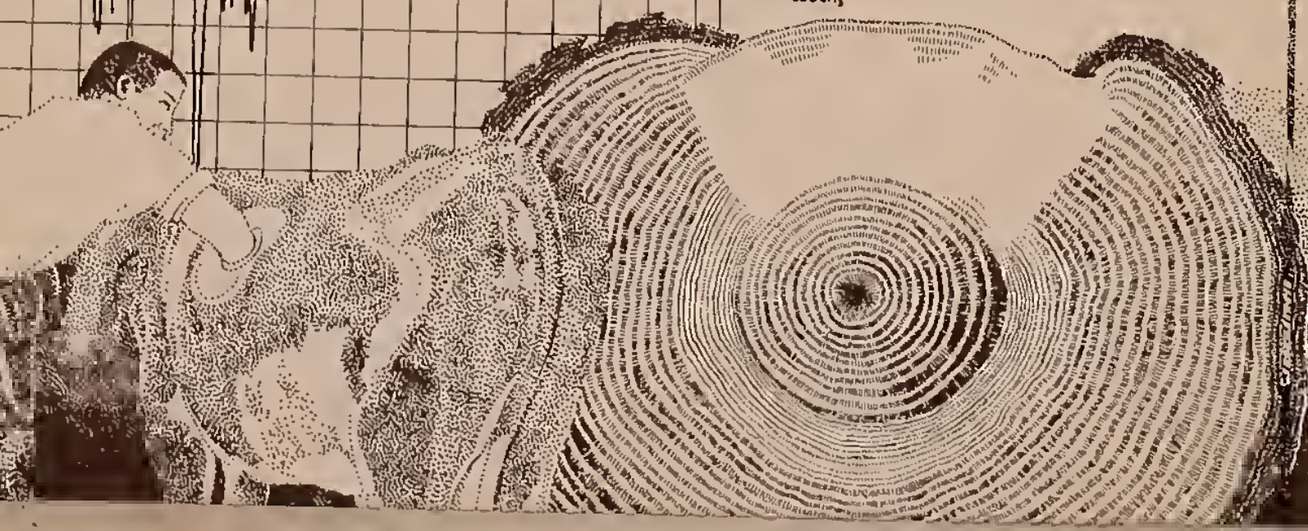
The major effort of WWII in chemical and energy research was toward the persistent problem of threatened fuel shortages. Intense pilot-scale wood-hydrolysis research improved yields of sugars for alcohol, reduced production time, and utilized more waste wood products. That process for production of energy from wood in the form of alcohol is still called "the Madison Process."

The period following the war years stressed applied research, resulting in refining the Madison Process for production of sugars, feed molasses, and yeasts. Work also turned toward derivation and characterization of the by-products and co-products of turpentine and naval-stores production methods.









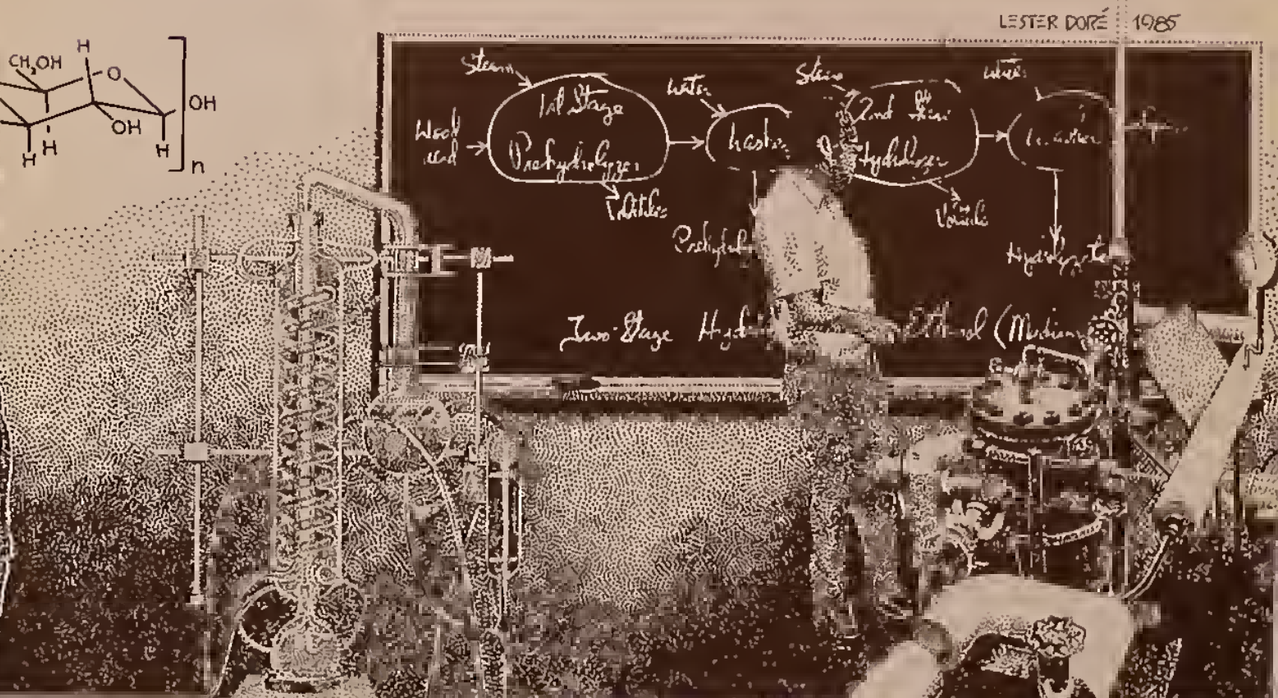
A turn to basic research, at a time of tremendous strides in the development of analytical techniques and equipment, led deeper into wood's molecular make-up. In the 1950's and 1960's, the lignin puzzle was slowly becoming better understood and the Lab was expanding the list of wood extractives from species around the world. Chemical studies of the molecular behavior of wood eventually contributed so greatly to the understanding of the phenomena in pulping and papermaking that several chemical studies eventually became integral parts of FPL's pulp and paper research. Efforts were renewed in naval stores research with emphasis on the chemistry, recovery, and analysis of naval stores by-products from kraft pulping.

World-wide tensions over fossil fuels in the 1970's resulted in the establishment of a group at FPL to study energy production from wood in all forms. The group has modified the Madison Process for further assessment; they have begun extensive studies to collect data on the uses of wood, wood alcohol and gasohol for fuels; they have cooperated with universities and industry in the production of feedstuffs from woods; they have assessed forest residues and the logistics of their use in chemical and other facets of forest products utilization.

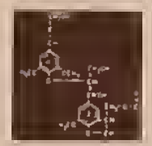
A collaborative effort in the 1980's has brought about the book *The Chemistry of Solid Wood*, which includes a basic summary of the chemical constituents of various species.

New, sophisticated analytical instruments are now allowing FPL researchers to refine their descriptions of wood's components on a more precise chemical basis, and to quantify their occurrence among species. This work will provide the basis for isolating, identifying, characterizing, and evaluating potential new products. Research is currently looking toward the recovery and utilization of black liquor and tall oil from kraft papermaking, and toward the production of new chemicals—including adhesives—from wood and its components.

This research continues to unlock the secrets of taking wood apart, releasing its energy in a variety of ways, and finding in it a renewable source of chemicals and energy.



Biotechnology



Whereas the Forest Products Laboratory took an early role in chemical and energy research, a logical offshoot, biotechnology, is a newcomer to the Lab's roster of research thrusts. Biotechnology—the manipulation of microbes and enzymes to produce useful biological reactions—is FPL's newest array of research interests combining wood and microbes.

The basics for the Lab's program of biotechnology in wood utilization were laid down throughout the first decades of the Lab's research in wood chemistry and wood decay. Years of work in the use of microbes in the fermentation of wood sugars to a variety of products formed the basis for FPL's involvement in biotechnology. It was the development in the early 1970's of the understanding of molecular genetics and the tools for tracking biochemical pathways that allowed researchers to undertake more specific projects.

The Lab's current activities in biotechnology began in 1970 with the objective of elucidating the biochemical mechanism of lignin degradation by wood-decay fungi. Researchers "followed" a typical wood-decay fungus into the wood cells and began to characterize the action by which the fungus could break down the lignin without breaking down the cellulose portion of the wood.

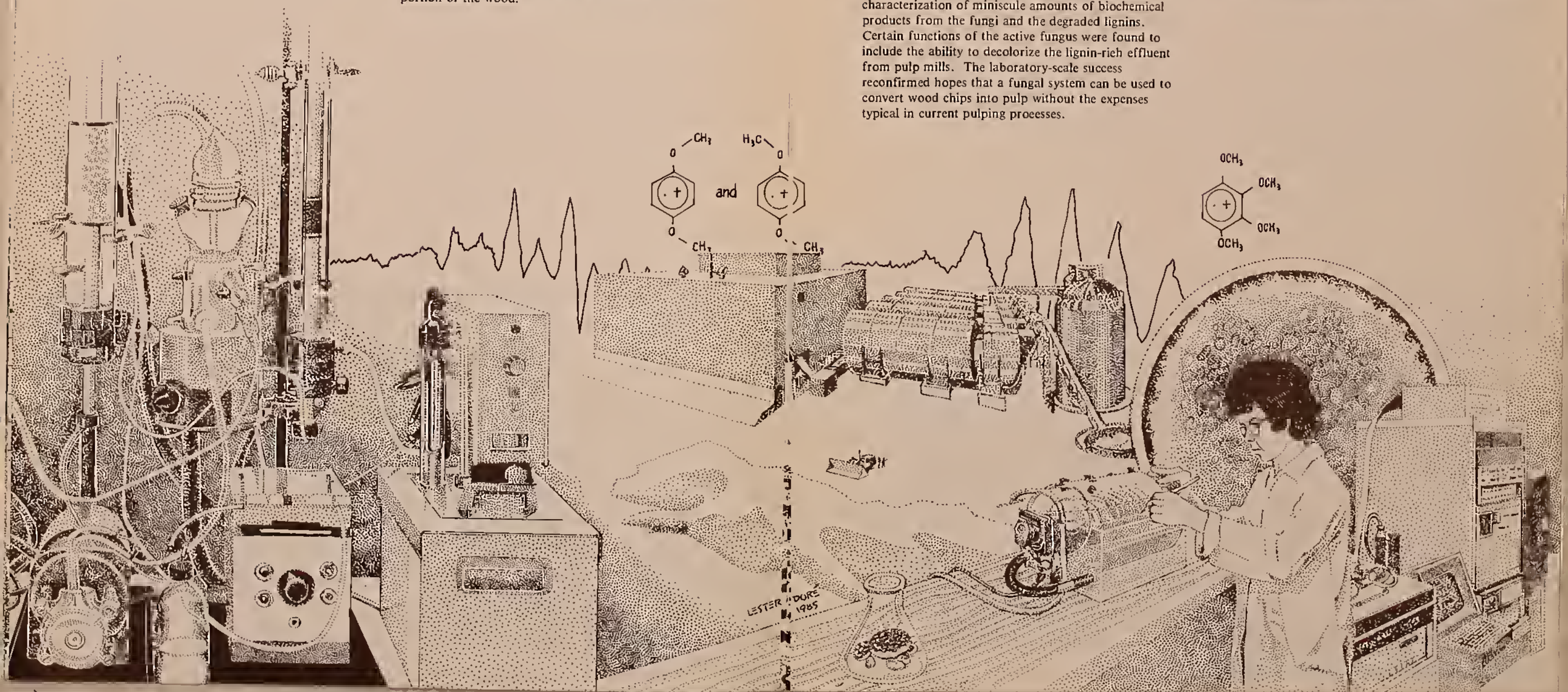
Because of the natural variability of wood and of the thousands of fungi that act on it, much research went first into understanding the optimum culture conditions for the growth and activity of selected fungi. This work was expanded upon very recently in the experimental cultivation of edible mushrooms on certain wood wastes—research aimed at utilizing more of our harvested trees, and the low-value ones.

Understanding the conditions under which microbes thrive was also an important question in the action of yeasts on wood sugars. Until recently certain abundant wood sugars resisted fermentation and contributed to waste. Success in manipulating culture conditions and screening hundreds of yeasts led to a select group that can ferment this "unusable" sugar.

Research on the biodegradation of lignin proceeded with the tedious isolation and characterization of miniscule amounts of biochemical products from the fungi and the degraded lignins. Certain functions of the active fungus were found to include the ability to decolorize the lignin-rich effluent from pulp mills. The laboratory-scale success reconfirmed hopes that a fungal system can be used to convert wood chips into pulp without the expenses typical in current pulping processes.

When research showed that degradation was via an enzyme system produced by the fungus for the sole purpose of degrading lignin, it opened up greater possibilities for biotechnology—in such processes as biopulping, biobleaching, and waste lignin conversions. Research began to identify more enzymes, to genetically manipulate fungi to enhance or alter their enzyme production, and to characterize the types of reactions they can effect in lignin.

Continued investigations into the intricate associations between microorganisms and wood will slowly but surely lead to the development of new biotechnical processes and new products for the wood and chemical industries. These newest forms and functions of wood in our lives will further broaden the world's perception of this infinitely renewable resource.



Mycology

Before the Forest Products Laboratory came to be, the U.S. Department of Agriculture was engaged in extensive research on microbial damage to forests and to structural timbers. Today FPL, as well as the National Forest System, relies on mycology research to help us balance our partnership with nature in using and maintaining our forests.

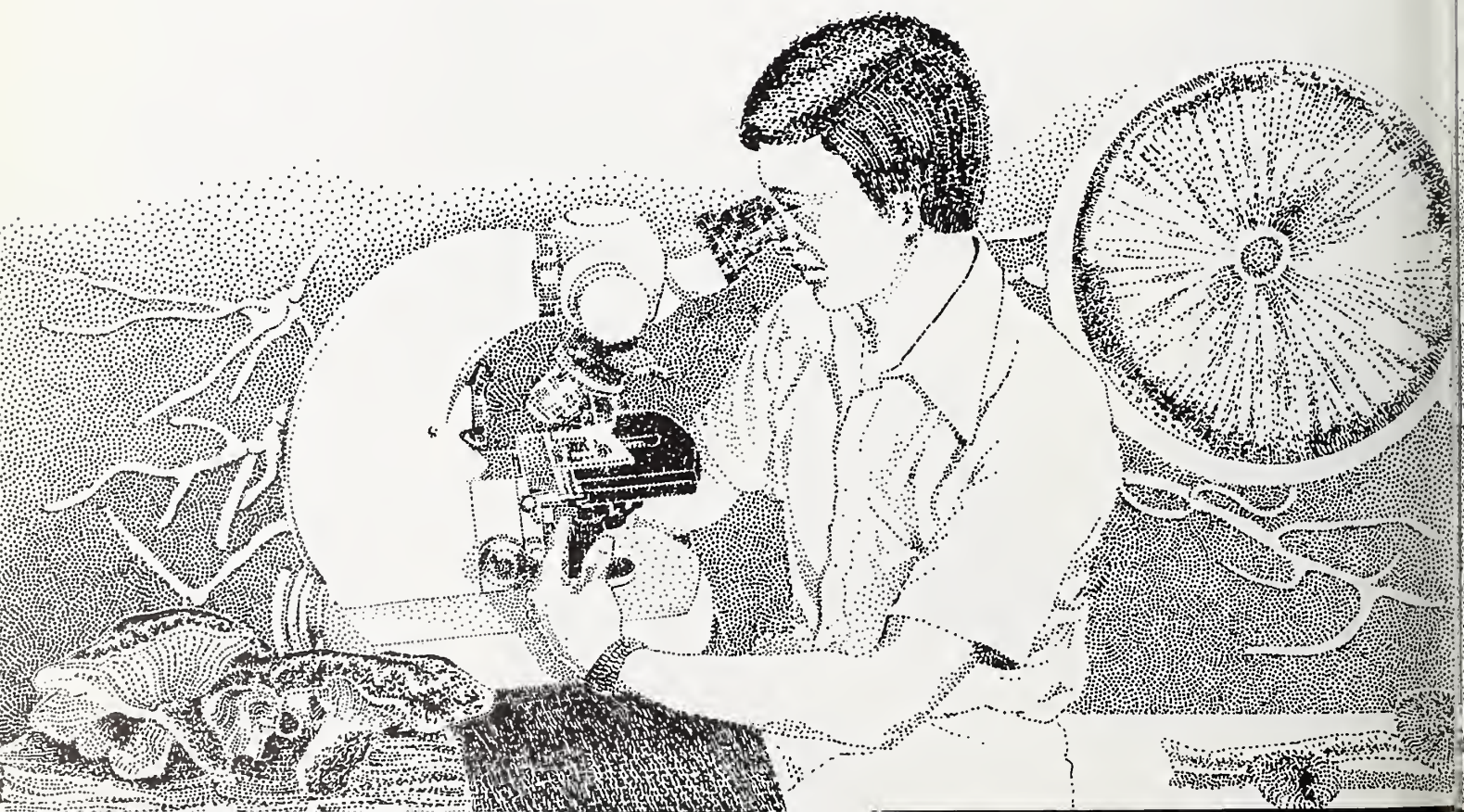
At the turn of the century a small, productive group at the Department's Mississippi Valley Laboratory in St. Louis set the tone for recognizing research needs, for identifying and categorizing the fungi and bacteria that invade wood and wood products, and for developing or improving preventative and preservative treatments. The work involved the beginning of the practice of collecting and culturing wood decay fungi.

When the St. Louis lab was disbanded in 1907, the remnants of the group continued their work in Washington, DC, where they handled a host of problems in applications research. Their concerns covered fruit, nut, ornamental, and shade trees, as well as nurseries, plantations, and forests.

The group's work in stain and deterioration of wood products resulted in one scientist being hired to work at the newly instituted FPL. The creation of that position established FPL's research in preservation and protection. Years later the mycology research group from Washington and the FPL pathology groups found themselves side by side at Madison.

The early research of the mycology group tended to be based largely on identification of decay by the appearance of the decayed wood. In the late 1920's, field researchers began to collect fungus cultures prepared from sporophores so that wood decay fungi found in the field could be compared with clean cultures of known origin and description. These collections served as the basis for the subsequent extensive collection of authenticated cultures at the group's headquarters.

The development of that collection led to several definitive papers in the late 1930's and early 1940's on the identification of fungi in culture, a development that emphasized the need for mycology as a distinct research program among the forest sciences. The concerns of the Forest Mycology Research staff were, by then,



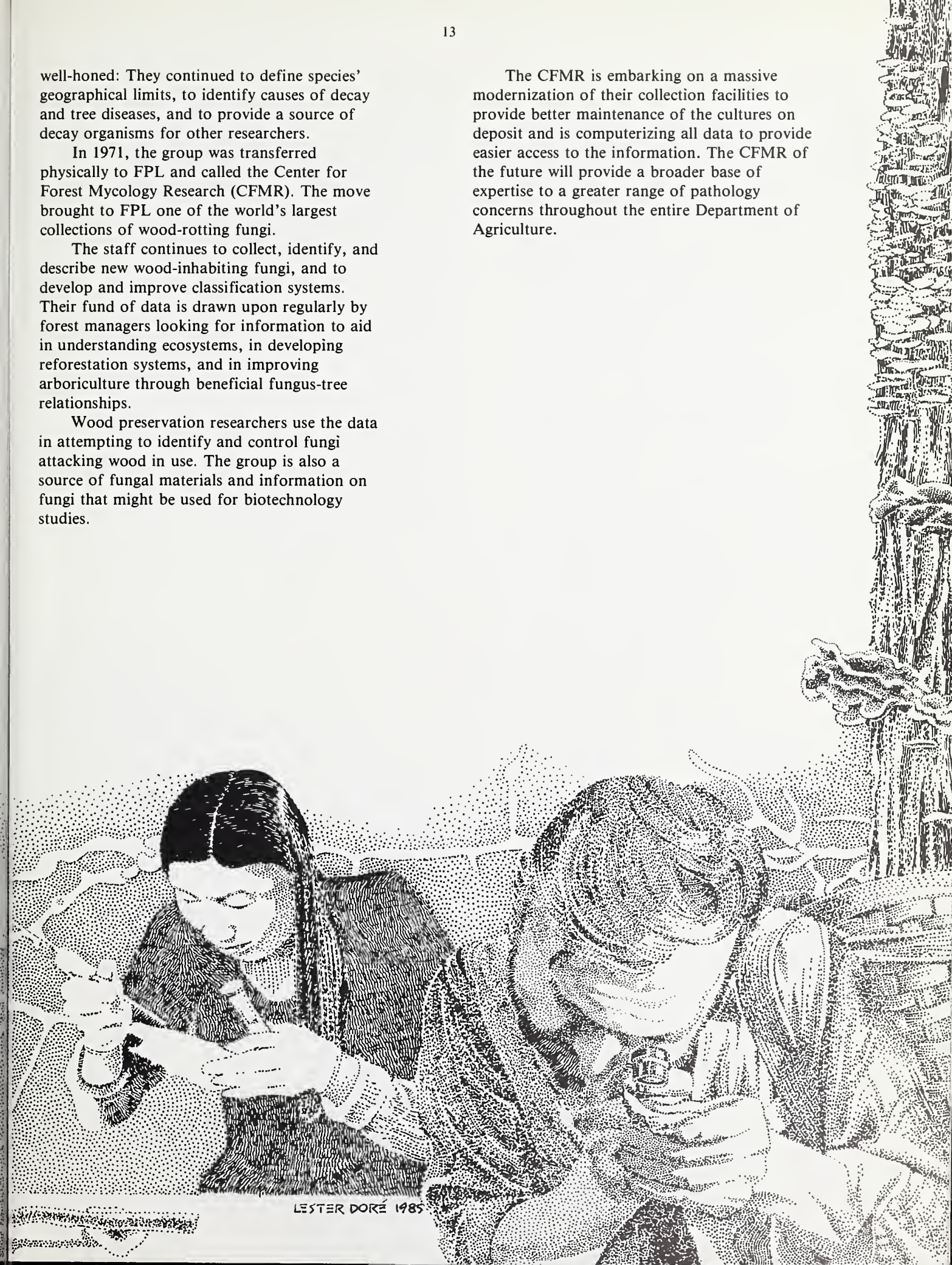
well-honed: They continued to define species' geographical limits, to identify causes of decay and tree diseases, and to provide a source of decay organisms for other researchers.

In 1971, the group was transferred physically to FPL and called the Center for Forest Mycology Research (CFMR). The move brought to FPL one of the world's largest collections of wood-rotting fungi.

The staff continues to collect, identify, and describe new wood-inhabiting fungi, and to develop and improve classification systems. Their fund of data is drawn upon regularly by forest managers looking for information to aid in understanding ecosystems, in developing reforestation systems, and in improving arboriculture through beneficial fungus-tree relationships.

Wood preservation researchers use the data in attempting to identify and control fungi attacking wood in use. The group is also a source of fungal materials and information on fungi that might be used for biotechnology studies.

The CFMR is embarking on a massive modernization of their collection facilities to provide better maintenance of the cultures on deposit and is computerizing all data to provide easier access to the information. The CFMR of the future will provide a broader base of expertise to a greater range of pathology concerns throughout the entire Department of Agriculture.



Pulp and Paper

Pulp and paper research at the Forest Products Laboratory began by exploring the feasibility of using various woods to meet a growing demand for pulp fiber. Today, FPL research is concerned with all aspects of pulp and papermaking, the largest single segment of the forest products industry.

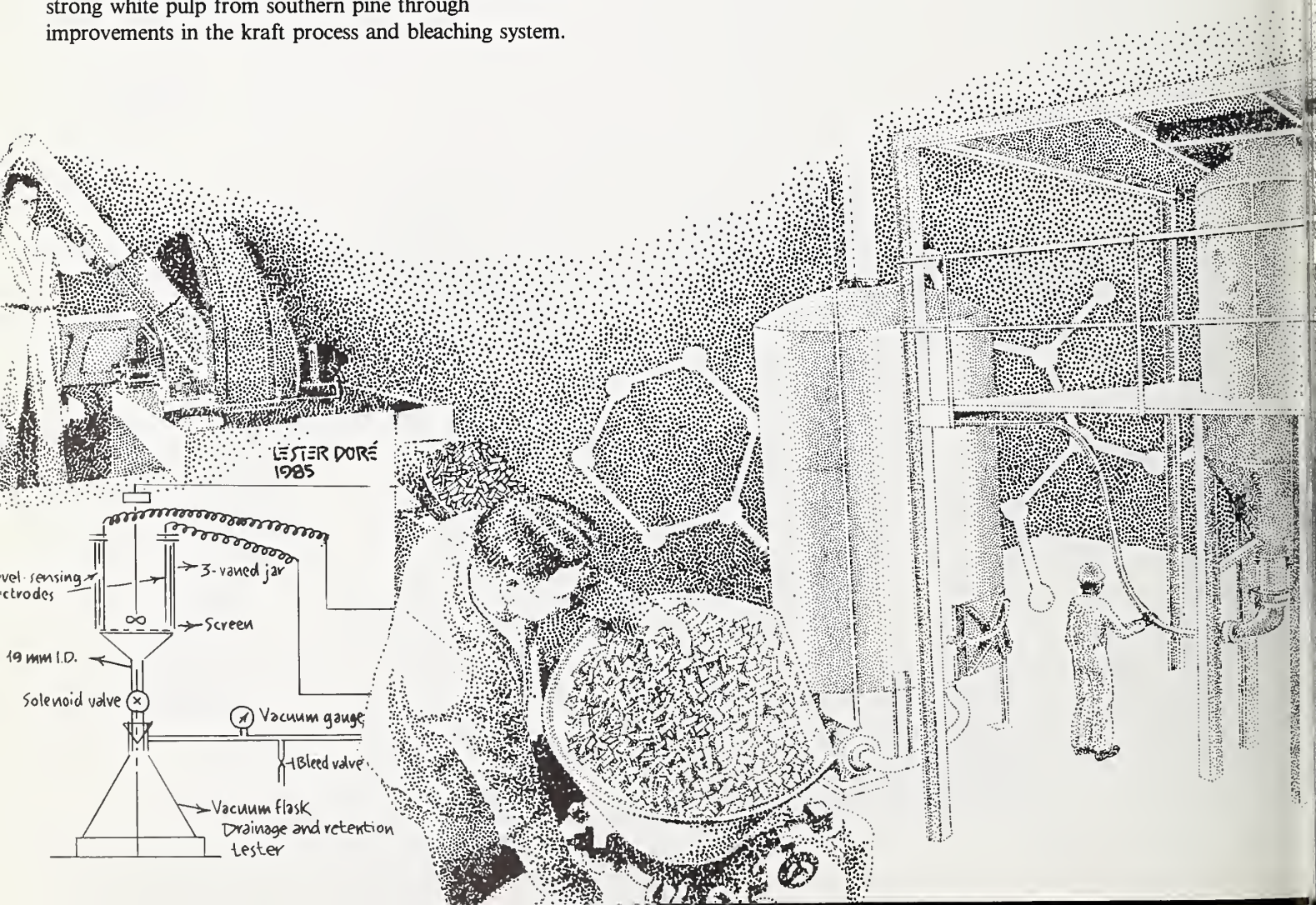
So great was the demand for groundwood at the turn of the century that U.S. pulp manufacturers were already looking to other countries to meet their needs. In an effort to make the best use of U.S. forest resources, the Forest Service stepped into the problem in 1906 to encourage the use of previously unused species. Consequently, when FPL first opened its doors, it featured a complement of pulp- and papermaking equipment.

Almost immediately the Lab built an experimental plant to establish better process controls, and to determine the suitability of a range of species for groundwood. The resulting list of acceptable species, the characterization and standardization of pulping conditions, and improved efficiency put the groundwood industry on solid footing.

After WWI, pulp and paper research burgeoned. Studies of temperature influence led to improved yield and quality in sulfite pulping; studies of fiber processing improved bleaching, beating, sizing, and refining. A significant development was a process for manufacturing strong white pulp from southern pine through improvements in the kraft process and bleaching system. More important, researchers learned how to combine chemical and mechanical procedures to reduce wood to fiber. This "semi-chemical" process, which enabled the production of pulp from hitherto unused hardwoods, revolutionized the pulp and paper industry.

A comprehensive program in the 1930's helped the southern pine paper industry to improve its white paper and to produce newsprint. Similar research on Douglas-fir was also successful. Research confirmed that growth conditions influence pulp quality, and reasserted the importance of forest management in optimizing forest utilization.

Efficiency and a broad material base remained the goals of pulp and paper research as America went to war in 1941. Recycling became an all-out effort. The armed forces sucked up pulpwood supplies for traditional uses and new ones. Pulping processes for "new" products paved the way for research into laminated plastics on a special paper base. Tough and dimensionally stable, this "papreg" found use in airplane construction and other wartime installations.



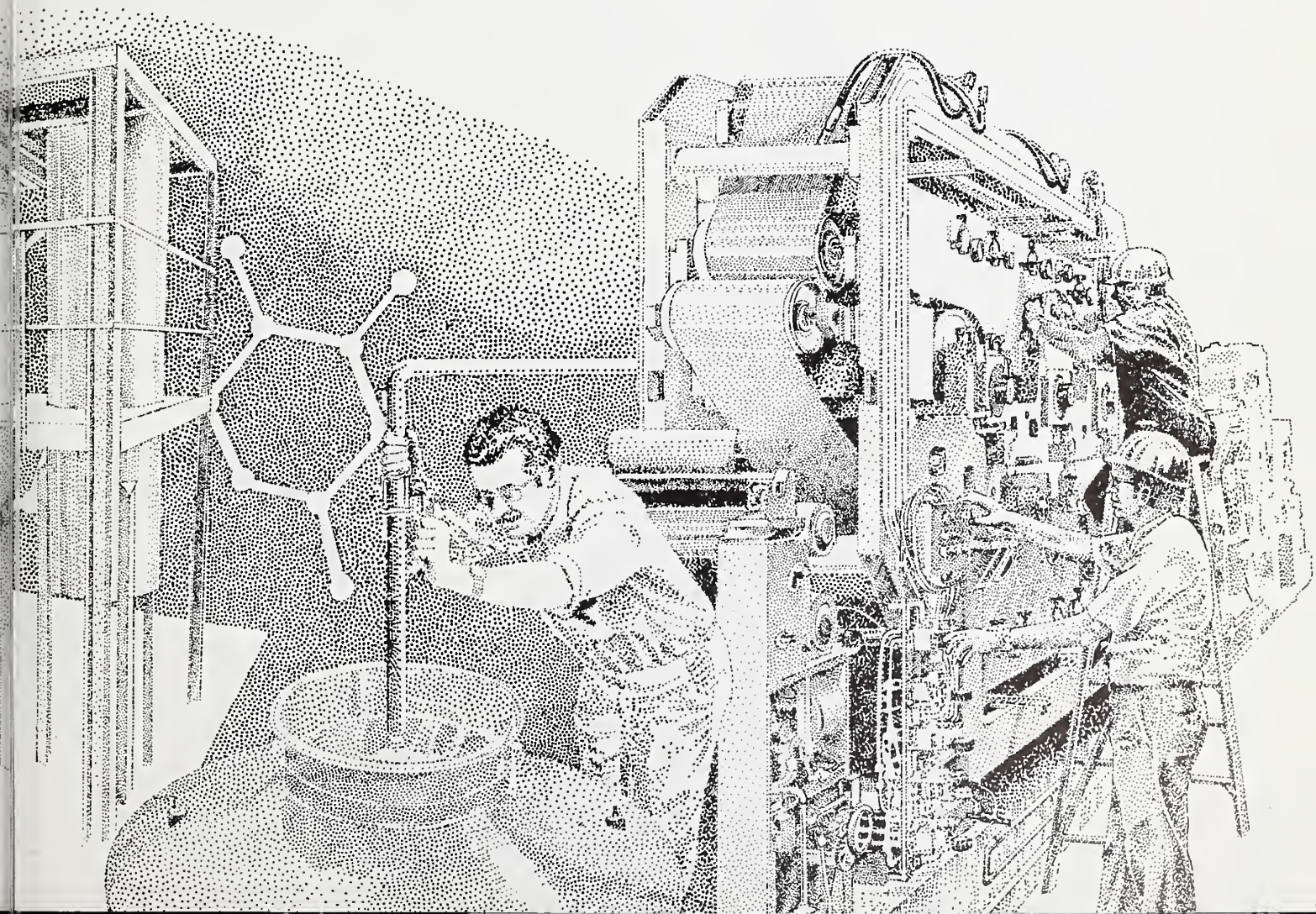
Research after the War explored the chemical reactions in pulping to increase yields and provide alternate pulping systems. Basic studies of fiber structure and bonding grew more active. These investigations were aided by sophisticated analytical instrumentation that included spectroscopy, chromatography, and microscopy.

In the 1960's, heightened interest in conservation led again to the pulping of recycled fibers. New concepts were developed for the thermal separation of plastics from wood fiber to enhance recycling of municipal wastes. The development of Press-Drying, using heat and pressure to improve fiber bonding, ushered in a new era of papermaking, permitting high-performance paperboard to be made from hardwoods. Chemical treatments were found to improve drainage, bonding, and sheet strength in hardwood and softwood pulps and to prevent and restore bonding losses in recycled fibers.

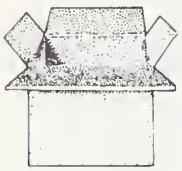
Ecological concerns encouraged FPL's investigations into oxygen pulping, identifying catalysts in the trace metals in wood, and finding "protector" materials to enhance pulp yield and strength, while reducing effluents. Research today at FPL is clarifying the role of certain chemicals in removing lignin during pulping.

A system to improve the wet strength and stiffness of paper is developing in FPL's SOFORM work. Based on chemical research of the 1940's, the process crosslinks pulp fibers with acetal bonds. Ideally, maintaining wet strength and stiffness will allow paper to be used in structural applications. One advance in the structural use of paper will come through FPL Spaceboard, a two-part unit of thick, molded, waffle-textured "paper" laminate with the strength and versatility to form building components or packaging materials.

All this will be underpinned by computerized databases of the reactivities of the wood/chemical components under bonding conditions. As we become better able to manipulate fibers we will be able to establish paper design criteria and engineering properties, and to alter the distribution of component polymers and particles in fibers. These advances will ensure the greatest efficiency as we witness the continued growth of this dynamic industry.



Packaging



The first packaging research at the Forest Products Laboratory involved designing wooden boxes to use less wood. Our goal today is the same as it was then—the highest performance of packaging at the least cost.

In the early days of the Lab, concerns from manufacturers and shippers led FPL research to prepare specifications for box testing and to design more durable boxes from less lumber and from underutilized species. Not surprisingly, it was the need to ship vast amounts of material to Europe during WWI that brought the War Department to FPL, looking first for species substitutes for wooden boxes. The Lab's response, based on years of accumulated wood property data, stimulated a profusion of war packaging research projects. Major concerns were better protection of war materiel, conservation of materials and cargo space, and less costly construction. The group overflowed into temporary additional quarters.

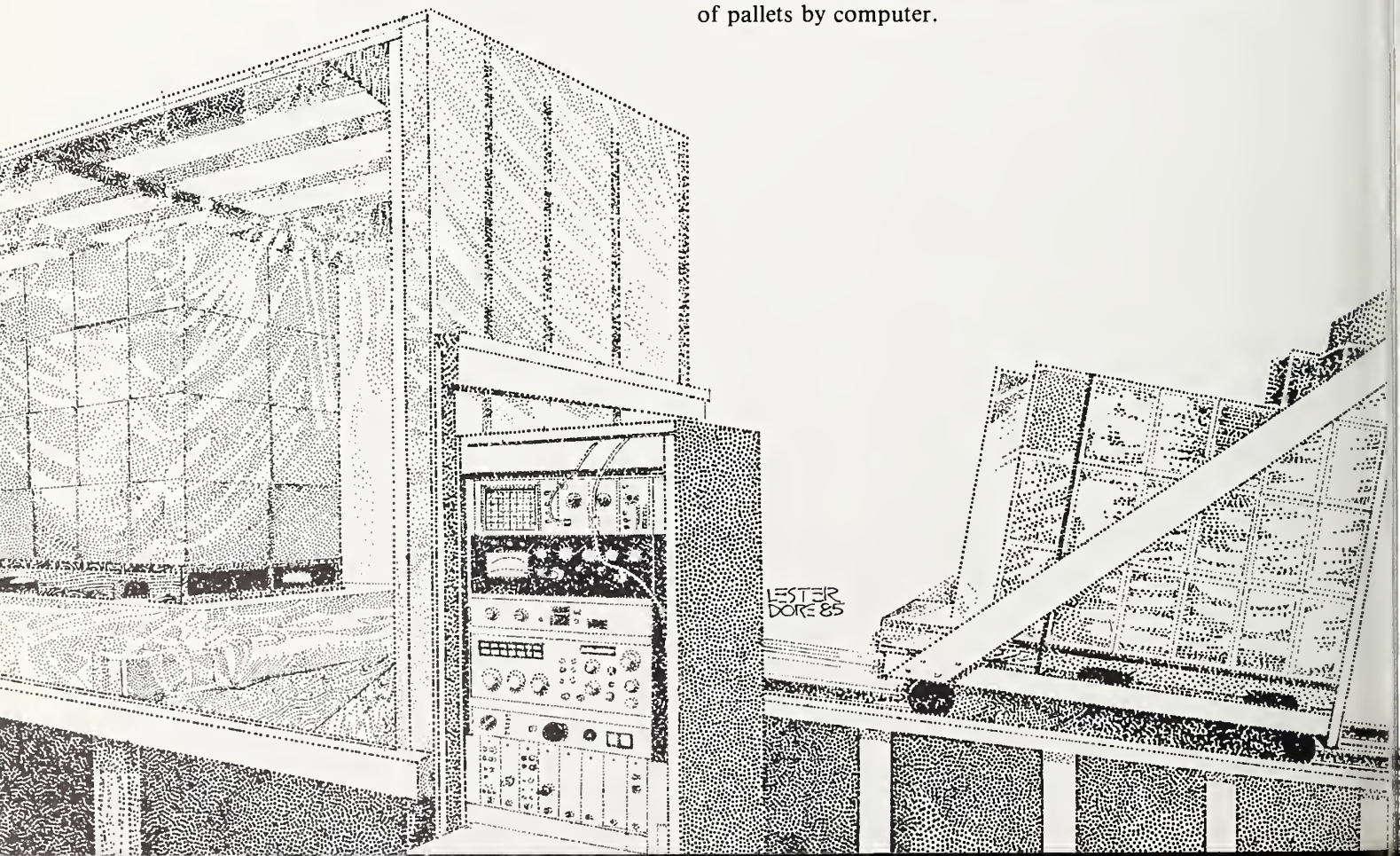
The combined needs and contributions of FPL and industry during WWI led, after the war, to a greater appreciation of the Lab's fund of data and to increased cooperation with industry in many fields.

When the market shifted to fiber-based containers in the 1920's, FPL responded with a comprehensive study of corrugated fiberboard and its component parts as engineering materials. In the absence of testing methods and equipment, FPL devised its own. The work yielded better understanding of the fundamental principles of design and improved quality.

When WWII broke out, FPL was ready again in packaging. The intensive research covered interior and exterior packing, corrosion-, grease-, and water-resistance factors, wood species, labeling, preservatives, adhesive tapes and pallets, and especially establishing packaging standards, replaying the military drama of 20 years earlier. Packaging personnel swelled the ranks of the FPL staff until, again, they sought temporary additional quarters.

After the War, we improved test methods to measure the basic strength and elastic properties of paperboard and developed classical engineering approaches to the design of corrugated containers.

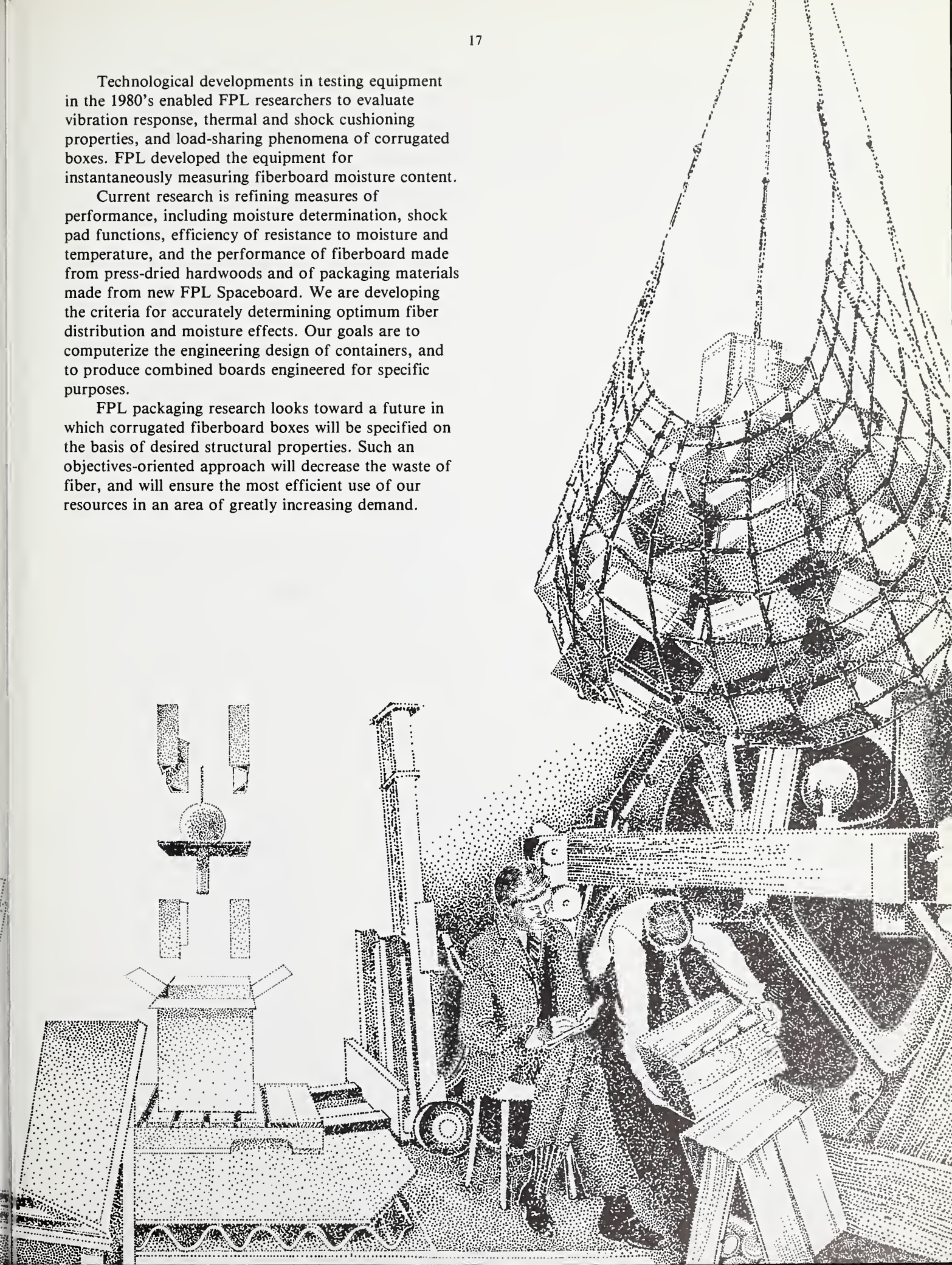
In the 1960's, pallet research was aimed at using underutilized hardwoods and at understanding the role of fasteners in pallet performance. Fiberboard research clarified performance standards and addressed the functions of cushioning materials. Interest in recycled papers in the 1970's brought about corrugated components made of secondary fibers. Production techniques were improved and box performance factors were better defined. Studies on impact resistance improved both corrugated boxes and pallets. Through the 1970's and into the early 1980's, Lab engineers provided baseline data and theory to permit the design of pallets by computer.



Technological developments in testing equipment in the 1980's enabled FPL researchers to evaluate vibration response, thermal and shock cushioning properties, and load-sharing phenomena of corrugated boxes. FPL developed the equipment for instantaneously measuring fiberboard moisture content.

Current research is refining measures of performance, including moisture determination, shock pad functions, efficiency of resistance to moisture and temperature, and the performance of fiberboard made from press-dried hardwoods and of packaging materials made from new FPL Spaceboard. We are developing the criteria for accurately determining optimum fiber distribution and moisture effects. Our goals are to computerize the engineering design of containers, and to produce combined boards engineered for specific purposes.

FPL packaging research looks toward a future in which corrugated fiberboard boxes will be specified on the basis of desired structural properties. Such an objectives-oriented approach will decrease the waste of fiber, and will ensure the most efficient use of our resources in an area of greatly increasing demand.



Anatomy and Identification

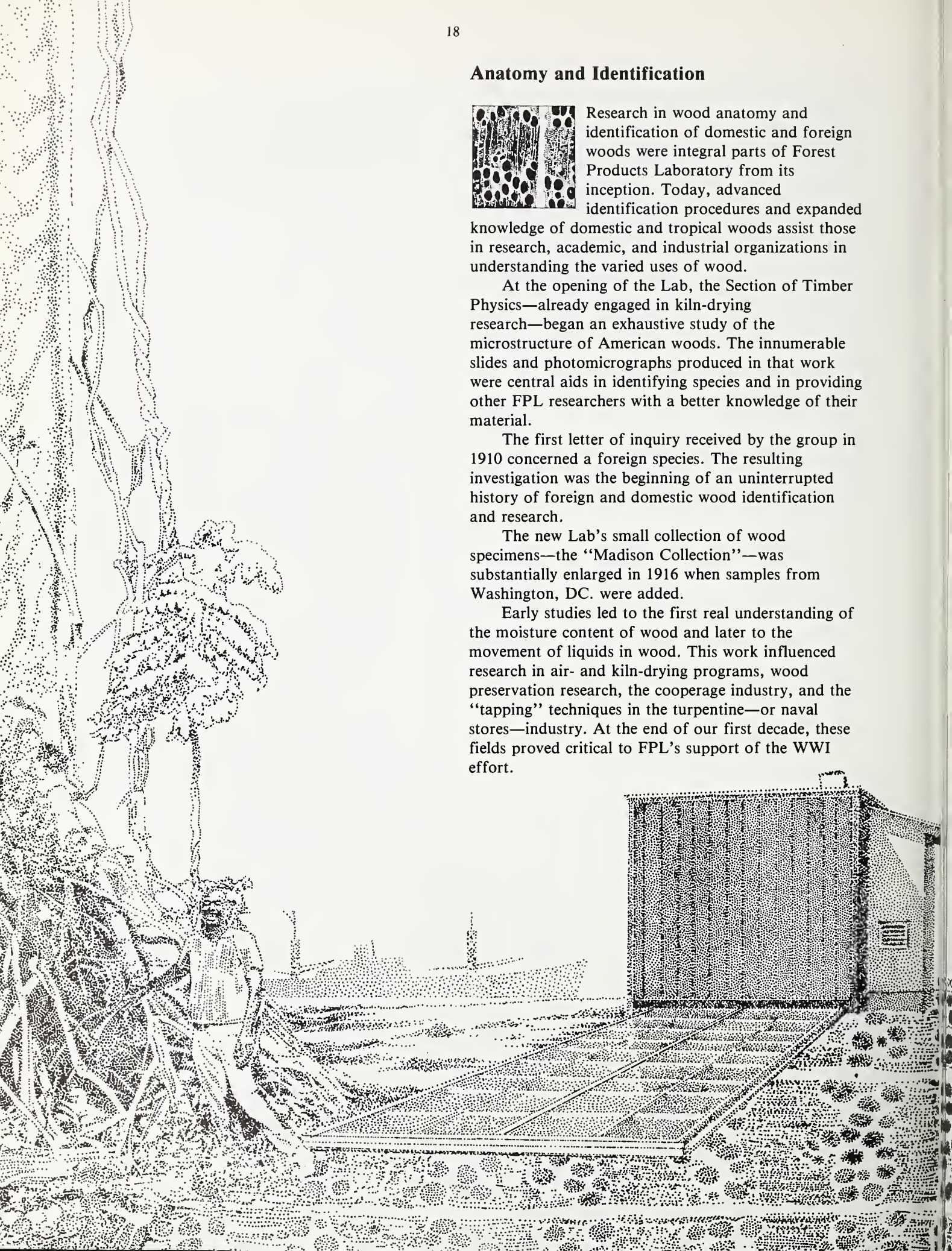
Research in wood anatomy and identification of domestic and foreign woods were integral parts of Forest Products Laboratory from its inception. Today, advanced identification procedures and expanded knowledge of domestic and tropical woods assist those in research, academic, and industrial organizations in understanding the varied uses of wood.

At the opening of the Lab, the Section of Timber Physics—already engaged in kiln-drying research—began an exhaustive study of the microstructure of American woods. The innumerable slides and photomicrographs produced in that work were central aids in identifying species and in providing other FPL researchers with a better knowledge of their material.

The first letter of inquiry received by the group in 1910 concerned a foreign species. The resulting investigation was the beginning of an uninterrupted history of foreign and domestic wood identification and research.

The new Lab's small collection of wood specimens—the "Madison Collection"—was substantially enlarged in 1916 when samples from Washington, DC. were added.

Early studies led to the first real understanding of the moisture content of wood and later to the movement of liquids in wood. This work influenced research in air- and kiln-drying programs, wood preservation research, the cooperage industry, and the "tapping" techniques in the turpentine—or naval stores—industry. At the end of our first decade, these fields proved critical to FPL's support of the WWI effort.



After the war, the relationship between forest growth conditions and wood quality led to a concerted effort in the 1920's to categorize the pine forests in the South and to use them to best advantage. FPL's work in the field was instrumental in the eventual establishment of Naval Stores Stations in the Southeastern United States. At this same time, the fund of knowledge at FPL in the microscopic characteristics of wood established the Lab's reputation for service in unusual areas. The Lab made headlines around the world in 1934 when FPL 'research' played a key role in the trial resulting from the kidnapping of the Lindbergh baby.

The war years of the 1940's demanded an emphasis on foreign wood supplies, as the Nation looked for substitutes for cork, rubber, and sponge, and for new sources of woods for container production. Emphasis after the War swung back to a concern for domestic supplies when we realized that some commercial timber was "second-growth," with different characteristics from our virgin forests. Wise use of this "new" wood called for an expanded definition of the structure of many common woods.

In the 1950's FPL continued its search into the identification, characterization, and utilization of foreign species. That work expanded the Madison Collection to 17,000 specimens, and expanded the Lab's reputation as an inexhaustible source of wood anatomy information.

Capitalizing on its reputation as a national center for forest products research, the Lab acquired the 55,000-specimen S. J. Record Memorial Wood Collection from Yale University in 1969. In 1970 a substantial wood collection from the Field Museum was added to the Madison Collection, bringing the Lab's total to over 100,000 specimens. The combined array is the largest in the world, and it continues to grow.

The group's work has continued to broaden the base of knowledge on tropical woods. Notable examples are the extensive collection of research papers describing the *Sapotaceae*, a predominant family of trees in the tropics, and a definitive handbook *Tropical Timbers of the World,* on the properties and uses of 370 species. Research from the anatomy group also interacts with other FPL research areas in improving processing techniques, such as kiln drying, to provide greater wood use options in their countries of origin.

As we move into the future, the wood anatomy unit has embarked on research to develop a system for computer-assisted wood identification and for retrieval of information on the Lab's 100,000 specimens. The gathering of data for wood identification will emphasize commercial species, but will eventually encompass all wood species. The staff will continue to update and improve the system. These functions will both aid in the group's own programs and make the Center more valuable to FPL and to the world of wood research.

Composite Products and Adhesives

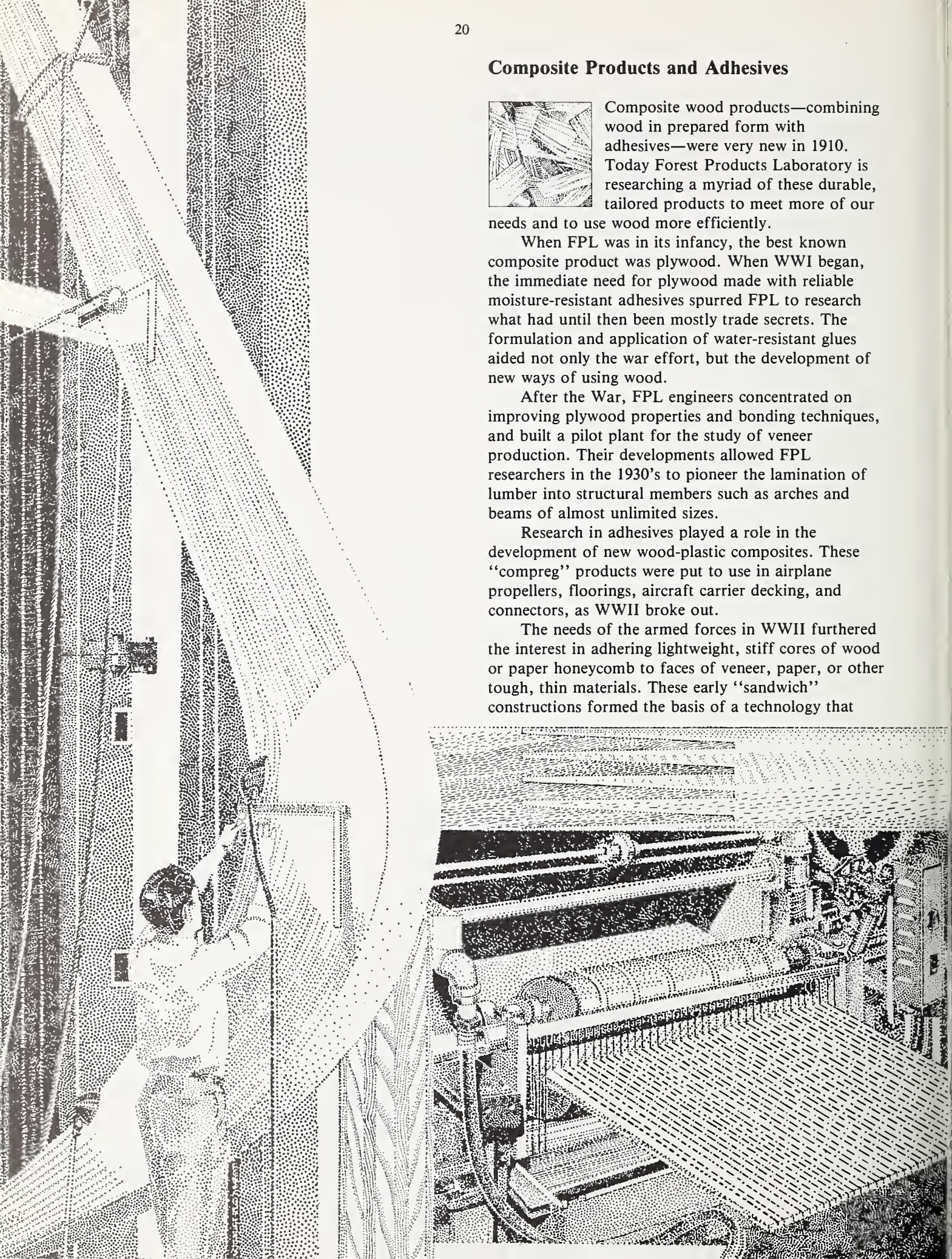
Composite wood products—combining wood in prepared form with adhesives—were very new in 1910. Today Forest Products Laboratory is researching a myriad of these durable, tailored products to meet more of our needs and to use wood more efficiently.

When FPL was in its infancy, the best known composite product was plywood. When WWI began, the immediate need for plywood made with reliable moisture-resistant adhesives spurred FPL to research what had until then been mostly trade secrets. The formulation and application of water-resistant glues aided not only the war effort, but the development of new ways of using wood.

After the War, FPL engineers concentrated on improving plywood properties and bonding techniques, and built a pilot plant for the study of veneer production. Their developments allowed FPL researchers in the 1930's to pioneer the lamination of lumber into structural members such as arches and beams of almost unlimited sizes.

Research in adhesives played a role in the development of new wood-plastic composites. These "compreg" products were put to use in airplane propellers, floorings, aircraft carrier decking, and connectors, as WWII broke out.

The needs of the armed forces in WWII furthered the interest in adhering lightweight, stiff cores of wood or paper honeycomb to faces of veneer, paper, or other tough, thin materials. These early "sandwich" constructions formed the basis of a technology that



eventually pervaded other areas of wood research, including housing components.

The decade after the War was devoted to the development of a new family of products known as particleboard. Composed of wood fibers, particles, or chips, they promised a limitless array of new wood forms and uses.

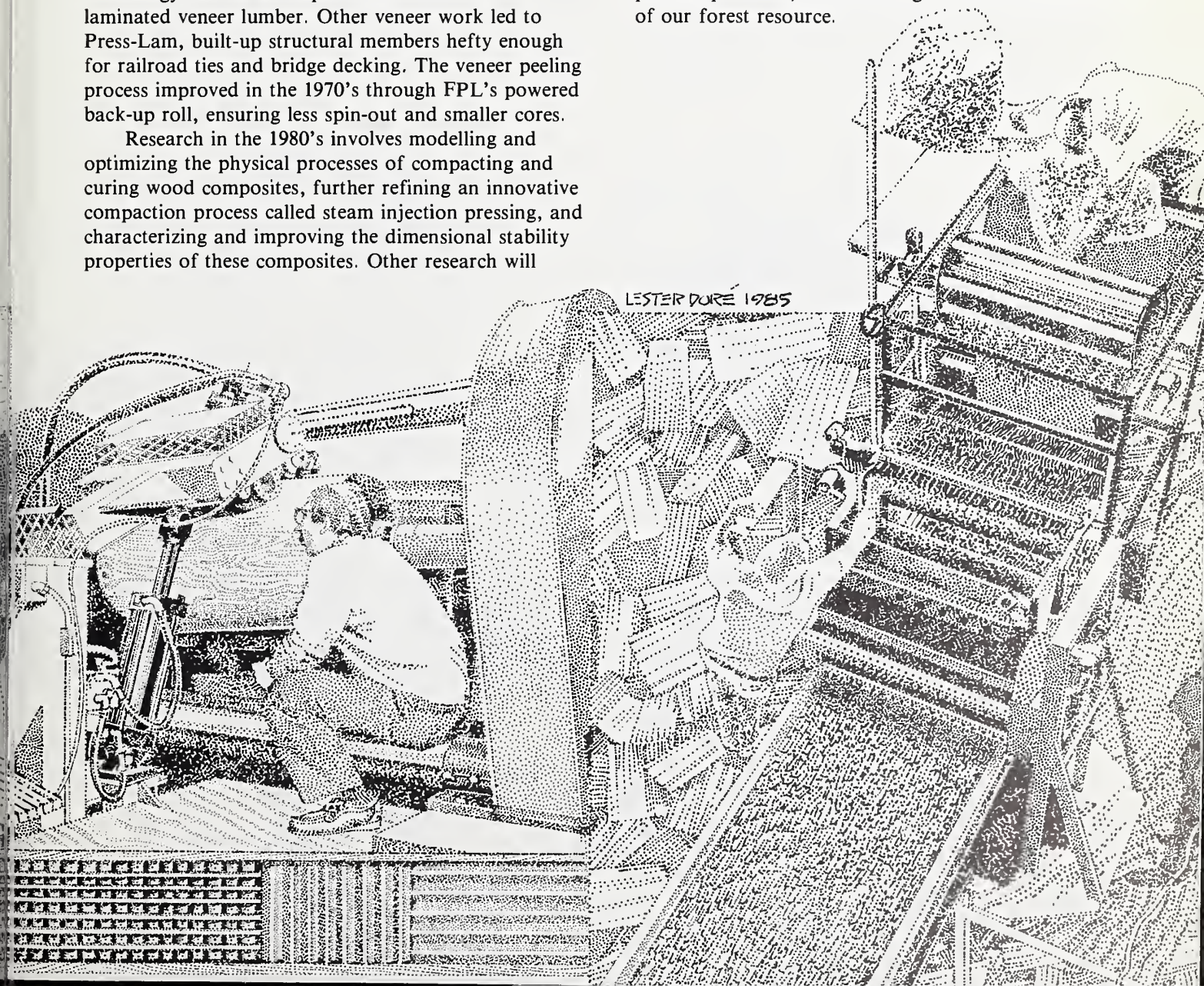
The 1960's witnessed the development of the southern pine plywood industry. FPL research determined the basic procedures for converting that underused species, thereby doubling the plywood resource base then limited to Douglas-fir. The Lab was instrumental in developing the information that provided the basis for standards needed by the new industry.

Success with structural material was furthered in the 1960's with the development of structural components from parallel-laminated rotary-cut veneer (PLV). The PLV material has been found to have greater uniformity and predictability than the same material in solid-wood form. The Lab's work provided technology for the development of standards for laminated veneer lumber. Other veneer work led to Press-Lam, built-up structural members hefty enough for railroad ties and bridge decking. The veneer peeling process improved in the 1970's through FPL's powered back-up roll, ensuring less spin-out and smaller cores.

Research in the 1980's involves modelling and optimizing the physical processes of compacting and curing wood composites, further refining an innovative compaction process called steam injection pressing, and characterizing and improving the dimensional stability properties of these composites. Other research will explore the possible use of alternative adhesive systems and will develop basic information on creep and duration-of-load properties of wood composites.

The development of new adhesives and new manufacturing technologies is opening up a number of new ways to improve wood utilization. FPL scientists are working with glued joints, shaped-sections, and in-plant application of preservatives and fire retardants. Engineering properties and end-use durability are being tested and design models are being developed to aid in the manufacture of these products. FPL chemists continue to seek solutions to such problems as formaldehyde emissions and the development of adhesives from renewable resources.

Future research will be shaped by the characterization of the chemical, physical, and mechanical properties of adhesives and wood elements during and after bonding, and of bonded structures during exposure in service. A continuing aspect of the research is to pursue neglected wood sources such as logging and manufacturing wastes and to assess their product potential, thus ensuring the most efficient use of our forest resource.



Timber Requirements and Economics

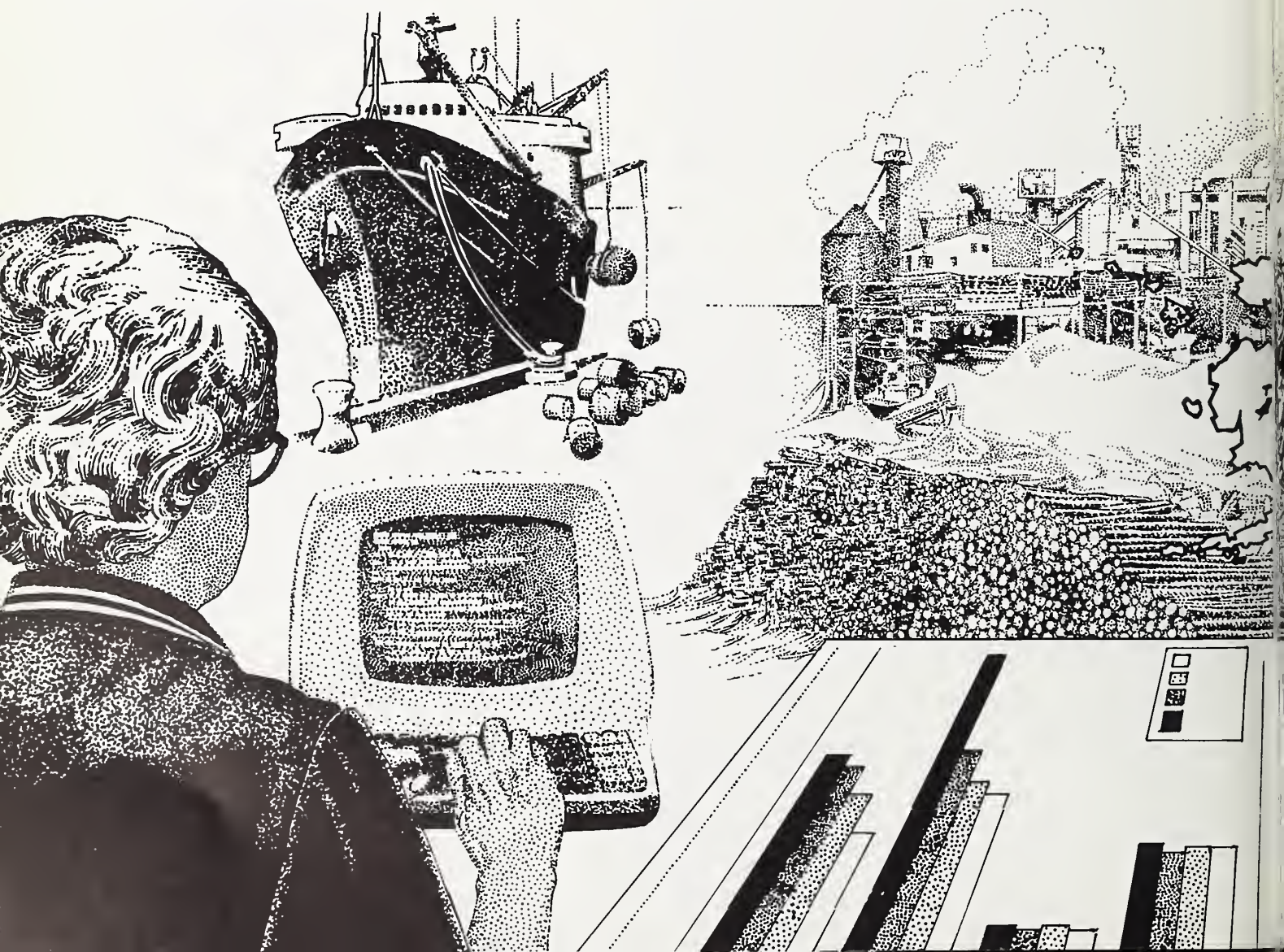
The need for a Forest Service was pointed up in the 1870's when a forest survey revealed the depletion of the Nation's wood resources. Economic research at Forest Products Laboratory now helps keep the nation abreast of trends in this important natural resource.

Indeed, the entire concern of this new agency was to balance the growth of the resource with its utilization. Much of the early function of the organization was to periodically assess the Nation's forested lands and the demand for forest products. In 1907 the Section of Wood Uses, headed up by a young man named McGarvey Cline, was charged with collecting forest products statistics and studying the market prices of products and woods used in various industries. The intent was to sustain liaison with industry so that the early forest products research would be directed toward practical problems.

Cline quickly found himself involved in the establishment of the Forest Products Laboratory and left Washington, DC, to become its first director. Not until 1920 did the Forest Service list an "economic investigations" group in its Directory, a result of legislation requiring an annual report of timber depletion, lumber prices, lumber exports, and certain industry demands and consumption. Such information was regarded as essential to the permanency and stability of industries, and to the safeguarding of the public against disastrous fluctuations and shifts.

In 1930 a nationwide survey of forest lands was begun to appraise timber supply and demand. That assessment emphasized "the critical need for pressing forward investigations in the relatively new field of forest economics." In light of the complex and paralyzing Depression, Forest Service officials saw the forest industries as a microeconomic community. They pushed for improved product markets and enhanced product quality along with efficient use and sustained yield, to stimulate at least the lumbering section of the Nation's economic recovery.

A "Reappraisal" of the U.S. forest resource after WWII alerted us to possible timber shortages and changes in the nature of the wood crop in the form of second-growth timber.



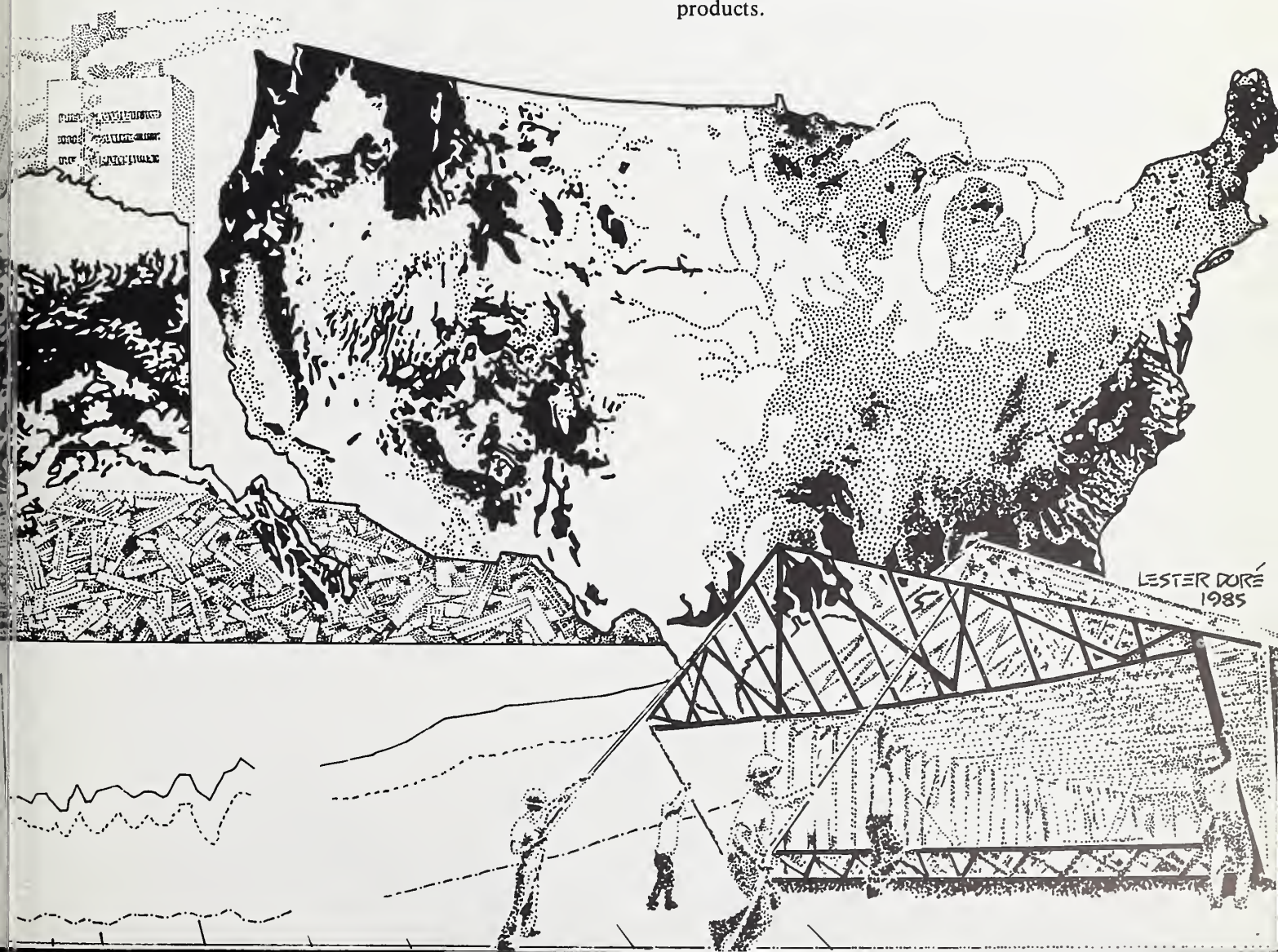
As the Forest Service stepped up its concern for regular forest resource assessments, more projects were "farmed out" to regional offices. It became apparent in the early 1970's that a group was needed devoted solely to evaluating trends in timber consumption and to evaluating the economic aspects of product and process development to estimate timber supply requirements. In 1975, a timber requirements research unit was established at the Lab as a permanent addition to forest products research.

Current wood use is studied at FPL to guide overall Forest Service planning as well as to guide FPL in pinpointing areas of research concern. Recent facets of that work have included assessments of timber products consumed for manufacture, mining, and fuel. Because housing is the largest consumer of lumber, plywood, and composite wood products, the Lab has developed a computer model for projecting U.S. housing demand. Other work is analyzing the uses of wood products in farm and commercial buildings and dams and highways.

A notable research mandate for the Lab is to determine the economic feasibility of new or improved products or processing methods, to help transfer new technologies into commercial use. Assessments have been made for new sawing methods, lumber defect detection methods, paper production methods, house-building systems, and other innovations. Such assessments translate the wise use of wood into the language of business.

An important thrust is still the original thrust of the early Forest Service: determining the economic relationship between timber supply and wood consumption. Typical of new large-scale uses of wood are the resurgence of wood-burning for residential heat, and the development of wood systems for house foundations. Economic studies of timber requirements not only help us understand changing wood consumption, but help in the overall management of forest lands.

This program will continue to watch new technologies to assess their impact on the resource. Research in the future will provide data on the requirements being placed on our forests. As with so many research areas, computers will become more sophisticated partners in sorting out the myriad influences in the economic health of our forest products industries and in the ability of our Nation's forest resources to meet our demands for wood products.



Processing of Lumber

The sawing and drying of lumber are perhaps the oldest and best known of the processes in wood utilization. By 1910, they were common practice with long and colorful histories and a variety of problems. Today, Forest Products Laboratory advances the processing of lumber on solid scientific foundations.

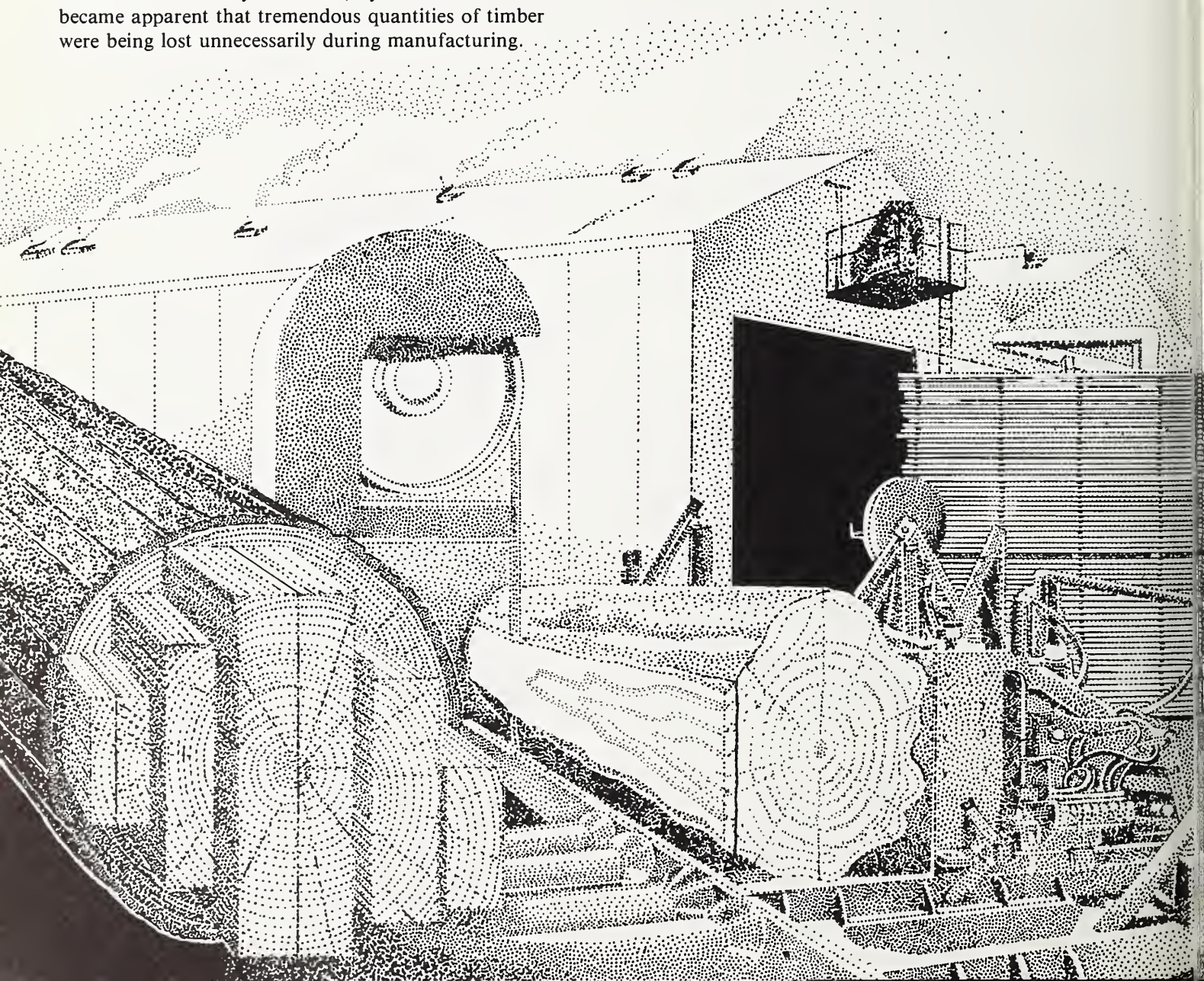
Sawing

Half a million years ago, humans began using the saw. That elemental instrument of civilization is today indispensable to wood-using industries around the world. FPL is the main institution in the United States today studying the methods and the efficiency of sawing wood.

In its first years, FPL did not focus on the subject of sawing because mills of that era were new and efficient for their day. However, by the 1920's it became apparent that tremendous quantities of timber were being lost unnecessarily during manufacturing.

To reduce that waste, FPL provided data to promote standardization of sizes, grades, specifications and nomenclature in lumber. Research during the Depression of the 1930's was aimed at helping small landowners and sawmillers through the publication of many handbooks on good logging, sawmilling, and business practices. The 1940's brought recognition of the need to improve sawing practices.

Concern for overall efficiency in the 1950's led to innovative research on saw operation, which gave the industry workable guidelines to operate saws more accurately with less power consumption. Such efficiency was complemented in the 1960's with concentration on defining log grades, and further increasing sawing accuracy and lumber yields. With skyrocketing stumpage prices, mechanical efficiency alone could not ensure that the most lumber was being recovered from each log. FPL researchers began intensive study of where to place sawlines in the logs for greatest lumber yield and highest quality.



During the 1970's, FPL encouraged exploration of the new idea of using electronic controls in sawing. The FPL Best Opening Face (BOF) computer program, which calculated where the sawlines should be placed for highest yield, gave the industry the impetus to adopt computer controls to automate sawmills. The result has been marked increases of lumber yield from the same volume of timber.

Researchers' further efforts in the 1970's included examining microwave, x-ray, optical, ultrasonic, capacitance, and nuclear magnetic resonance techniques to locate board defects. When lab-scale success was achieved with ultrasonics, researchers developed computer models to make ripping and cross-cutting decisions that would help lumber users, such as furniture plants, to better utilize their raw material.

As the investigations into production efficiency continued in the 1970's, computer modelling resulted in programs for improved millwork yield. Two processing systems for increasing lumber yield were Edge, Glue, and Rip (EGAR), in which small logs are made into larger, stable joist material by a novel sequence of sawing, drying, edging, gluing, and resawing, and Saw-Dry-Rip (SDR), in which small hardwoods are manufactured into structural lumber by sawing and drying flitches, then ripping to final dimensions, which greatly reduces lumber warping.

Computers have made it possible to bring about the Sawmill Improvement Program (SIP) developed at FPL in conjunction with State and Private Forestry. The program helps sawmills to assess objectively their productivity and efficiency.

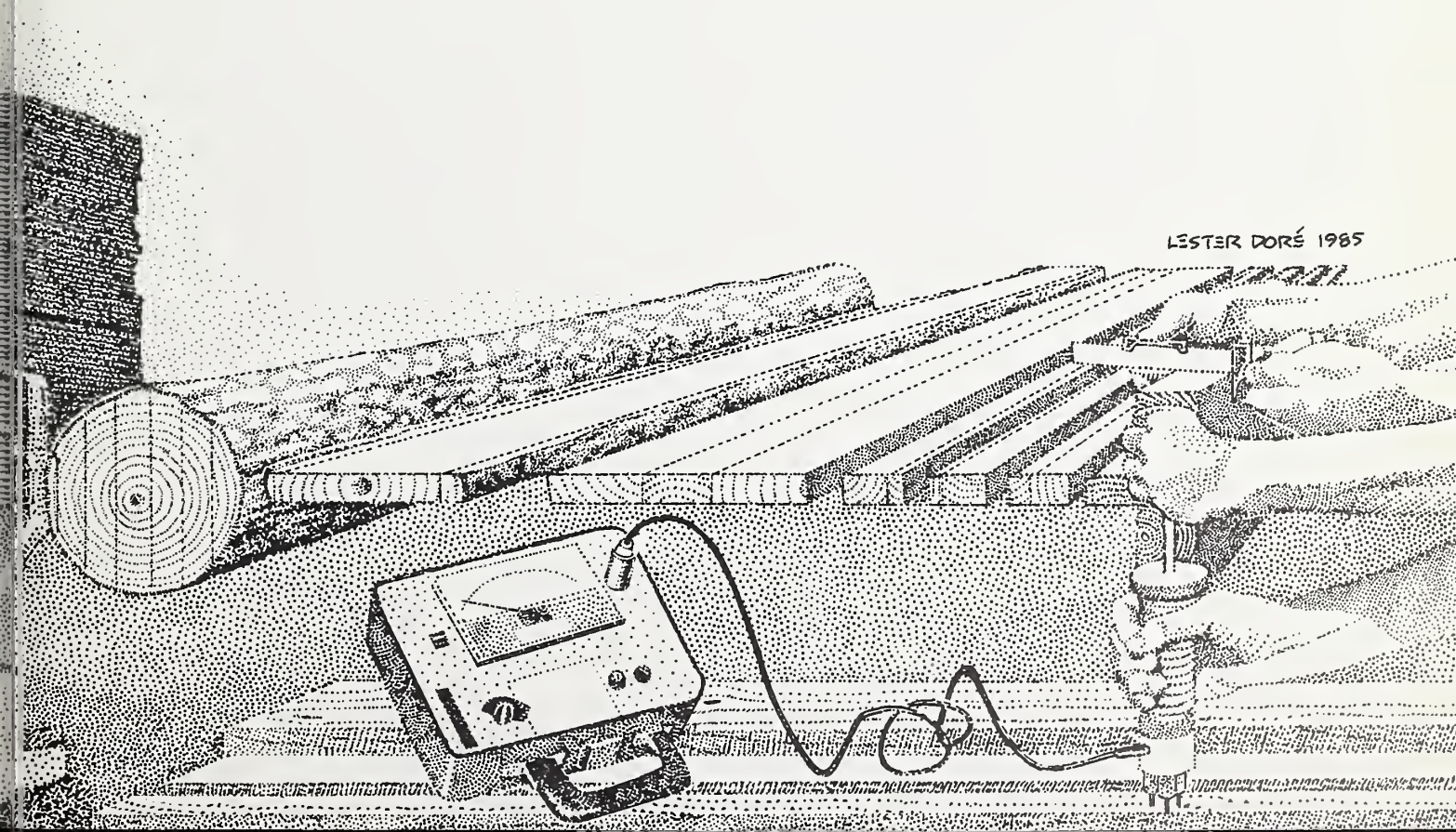
In the future the foundation laid by past research will be built upon to better understand the basic mechanics of the sawing process. This research will analyze the effect of wood anatomy, cutting forces, and saw operating conditions on the cutting process, enabling sawmills to better utilize each tree.

Computers will continue to play increasingly sophisticated roles in the improved efficiency of the milling of lumber, making decisions, moving logs and lumber, and planning for the future. New tools, such as lasers, to manufacture lumber with little waste will be developed. Whatever the methods, FPL's goal will be unchanged: to provide the greatest amount of usable lumber and fiber from each harvested tree, ensuring the longevity and productivity of our forests.

Drying

The drying research staff arrived at FPL in 1910, intent on improving the quality of wood dried by a new technology—the dry kiln. Now, FPL drying research still works to dry wood better and faster with conventional, solar, and vacuum kilns, hot presses, and other technologies of a newer era.

Research in the first years concentrated on the basics of wood moisture-humidity-temperature relationships, exploring the principle of controlling humidity to safely dry wood. Improvements in understanding and using the water-spray kiln helped meet the tremendous demand of WWI for dry walnut and oak for gunstock and caissons, and for dry spruce and other species for airplane parts.



The 1920's formalized information on wood-moisture relations. FPL's internal-fan kiln—at first cobbled together with office fans and later refined through research—formed the basis for industry's finely controlled commercial kilns. The Lab pioneered research that led to the development of the electrical-resistance moisture meter, an indispensable tool for the quick, accurate determination of moisture in lumber. Charts for gauging appropriate "equilibrium moisture contents" (EMC's) followed, providing kiln operators with the major tools for efficient lumber drying. An associated project studied lumber yards and established standardized moisture content levels for specific products.

Seasoning took a different turn in the 1930's, with the use of chemical baths, altering wood slightly to speed up the drying process. New and revised schedules reduced drying time and made kiln drying an option for more species. Information on the influence of moisture on wood strength was an important contribution to FPL's *Wood Handbook*.

Chemical seasoning was applied in WWII to Douglas-fir for pontoon stock for transporting war material. When the War effort demanded more high-quality lumber as fast as possible, FPL undertook to certify commercial kilns for drying lumber without strength losses, for gliders and airplanes. The group determined that kiln design influenced drying performance.

The housing demand of the 1950's put renewed emphasis on standards and, therefore, on educating kiln operators and lumber dealers. The effects of drying on internal stresses of lumber were studied, helping to establish safely accelerated kiln schedules for all domestic hardwoods. The Lab began to correlate data on long-practiced but little-researched air-drying. The products of those concerns were the publication in the 1960's of definitive books on kiln and air drying. A third major publication covered drying techniques for developing countries.

More FPL groundwork was covered in the 1970's with a manual on proper storage of lumber. Efforts to use underutilized species formed the impetus for studies of drying certain hardwoods. Continuing concerns for lumber quality supported research into one of nature's odd products, "wetwood," a frequently occurring bacterial infection in woods that can adversely affect drying practices. At the same time, in cooperation with FPL's engineering and composite products researchers, the group experimented with the drying of veneers in a range of thicknesses, by a variety of methods, including FPL's Press-Lam process.

Interest in the drying phenomenon and alternate energy sources have come to the fore in the 1980's with intense research into the design and efficiency of solar kilns. Other technologies under study include press and vacuum drying, with tremendous benefits in speed, and dehumidification drying for smaller operators. FPL is also looking at drying as part of integrated processes combining sawing and gluing, to overcome multiple problems in manufacturing lumber from certain woods.

As research reduces the time required to dry wood, FPL will be exploring acoustic emission technology and other sensitive, increasingly sophisticated measures of wood's response to drying. Computers can then link critical drying stresses detected by acoustic emissions to kiln control as an early warning signal, effectively preventing drying degrade. These efforts will help ensure the highest quality in the products coming from our Nation's forests, and the most efficient meeting of our demands for wood.

Epilog

We have touched here on some of the research accomplishments of the USDA Forest Service, Forest Products Laboratory.

The tangible products of this research are thousands of publications, including highly complex treatises, definitive handbooks, and how-to brochures. The intangible products are the advancement of science in the basic understanding of wood, and the education of thousands of students.

These successes have benefited individuals, through personal responses to questions and problems; the general public, through publications on better, safer uses of wood products; and industry, through information to ensure the efficient, economical use of our Nation's wood resources.

It is the vision and talent of the people at FPL that have made the Lab a vital and responsive whole. Our performance has been complemented by our associations with professional organizations, academic institutions, industry, other Federal agencies and departments, foreign laboratories, and honorary societies furthering excellence in research.

Our achievements and these associations are essential to the building of a research institution; they are the cornerstones upon which public trust and professional credibility rest. On this solid foundation, we look forward to a future of additional creative, innovative contributions to the wise and efficient use of our forests.

Explanation of the Drawings

Cover. The main building at the Forest Products Laboratory.

People. Among the many faces of those who have worked at the Forest Products Laboratory are those who have served as its Director: In the background are McGarvey Cline, 1910-1912; Howard F. Weiss, 1912-1917; Carlisle P. Winslow, 1917-1946; George M. Hunt, 1946-1951; J. Alfred Hall, 1951-1959; Edward G. Locke, 1959-1966; Herbert O. Fleischer, 1967-1975. In front of them is Robert L. Youngs, 1975-1985; and in the foreground is John R. Erickson, 1985- .

Material Properties and Construction. Inset: Screw patterns in fastener research. Long-span bridge using preservative-treated, structural glued-laminated timber; evaluation of the strength-of-wall systems under fire exposure; evaluation of a house under simulated wind and snow loading; the Truss-Framed System for rapid construction of strong, economical housing.

Preservation and Protection. Inset: Termites. Timed fire resistance test; insects (termites) attacking wood; inspection of wood-finish test panels; pier showing pilings attacked by marine borers; cellulose chemical structure with modifications, overlaid by close-up view of wood; railroad ties coming out of a preservative treating cylinder.

Chemicals and Energy. Inset: Round-bottomed flask. Infrared spectrum and structure of compound derived from wood; fistulated cow used in research on animal feed from wood; chemical structure of cellulose; wood "lightered" by paraquat treatment; apparatus to concentrate pulping liquors; scheme for the two-stage dilute acid hydrolysis of wood to produce sugar for ethanol production; equipment for testing the first stage of the two-stage dilute acid hydrolysis of wood.

Biotechnology. Inset: Lignin chemical structure. Laboratory fermentation apparatus for yeast conversion of wood sugars; mechanistic studies of lignin-degrading enzymes; artist's conception of a biological pulp mill; edible *shiitake* mushroom on a chemical medium; fungal decolorization of pulping effluent; selection of superior yeast strains for fermenting wood sugars; mass spectrometer used to identify metabolites.

Mycology. Inset: Shelf-like structures formed by fungi. Fungal threads (hyphae) as they appear microscopically; mushroom decaying a piece of wood; microscopic examination of broth cultures and fruiting fungi from nature; fungi growing on petri dishes with nutrient media; establishing cultures in test tubes for study; collecting fungal specimens in the field; conks—shelf-like structures—on a standing dead tree.

Pulp and Paper. Inset: FPL Spaceboard. Converting pulpwood into chips; pulp drainage and retention tester; lignin and carbohydrate chemistry; loading chips into digester; new digester with blowtank; removal of contaminants with spinning disk; making press-dried paper.

Packaging. Inset: Corrugated fiberboard container. Vibration testing of unitized load; shock testing of unitized load; corrugated fiberboard cushioning design; forklift impact panel to reduce damage to wooden pallets; revolving drum for determining the durability of wooden boxes, crates, and pallets.

Anatomy and Identification. Inset: Transverse section of white oak. Tropical hardwood species with stilt roots, fluted buttress, and attached lianas (vines); solar kiln designed to dry lumber in tropical locations; photomicrograph of transverse (cross) section of white oak *(Quercus alba)* at low magnification; computer-assisted wood identification.

Composite Products and Adhesives. Inset: Waferboard panel. Glued-laminated arch being tested; glued structural finger joint; application of adhesive on veneer sheet; 7-ply plywood panel; sandwich panel; veneer lathe and powered back-up roll; sheet of waferboard; flake forming and aligning machine; aligned flakeboard mat.

Timber Requirements and Economics. Inset: Plotting timber projections. Computerized analyses of the demand for forest products; world trade in paper products; economics of pulping technologies; graphing production statistics; identifying forest resource distribution patterns; economic analyses of new products and technologies such as composite panels and the Truss-Framed System of construction.

Processing of Lumber. Inset: Computer control for sawing wood. Maximizing lumber yield with Best Opening Face; development of sawing methods; kiln drying methods improvement; Edge, Glue, and Rip manufacturing; measuring wood moisture content by electrical resistance.

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Facilities of the Forest Products Laboratory

1909	A house at 1610 Adams Street near the University of Wisconsin campus becomes temporary quarters.
1910	All staff and machinery move into the new Forest Products Laboratory at 1509 University Avenue, on land donated by the UW.
1917-1919	World War I research requires space in part or all of 10 UW buildings.
1932	Post-WWI crowding is relieved when a new 188,000-square-foot building is constructed off Walnut Street at the west end of the campus, on land donated by the UW.
1934	Packaging research gains space with construction of a building supported by laminated arches.
1935	Composite products research moves to a new building constructed with experimental siding to test finishes.
1943-1945	Expanded World War II research finds space on three floors of a downtown building at 120 S. Fairchild Street.
1956	The Laboratory establishes a rural exposure site near Madison to evaluate wood products.
1967	The innovative new Pulp & Paper Pilot Plant and its complementary Fiber Research Building increase FPL space by 90,000 square feet.
1969	The new Chemistry Research Building completes the trio with another 32,000 square feet.
1974	The acquisition of several small buildings from the nearby Wisconsin Alumni Research Foundation provides more space for engineering research.
1982-present	The weatherization and modernization of the 1932 building includes energy-efficient windows, improved utility systems, and more work space in basement areas.

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